TEXTBOOK OF MECHANICAL ENGINEERING

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CONTENTS

Part I.—Workshop Practice

CHAPTER I

Metals Used in Mechanical Engineering

CHAPTER II

Mechanical Drawing

CHAPTER III

Production of Castings

CHAPTER IV

Blacksmiths' Work

CHAPTER V

Boilermakers' Work

CHAPTER VI

HEAT TREATMENT

CHAPTER VII

SOLDERING, BRAZING AND WELDING

CHAPTER VIII

FITTERS' SHOP WORK

CHAPTER IX

MACHINE-SHOP WORK

CHAPTER X

Wood-Cutting Machinery

CHAPTER XI

Workshop Economics

Part II.—Heat Engines

CHAPTER XII

Elementary Thermodynamics of the I.C. Engine.

CHAPTER XIII

Practical Strokes and Valve Timing

CHAPTER XIV

Types and Rating of I.C. Engines

CHAPTER XV

Governing, Lubrication, Air Filtering, Cooling and Silencing of I.C. Engines

CHAPTER XVI

Gas Engines and Producers

CHAPTER XVII

Petrol Engines

CHAPTER XVIII

Oil Engines

CHAPTER XIX

Heavy-Oil Engines

CHAPTER XX

Overhaul of I.C. Engines

CHAPTER XXI

Steam Boilers

CHAPTER XXII

Care, Working and Management of Boilers

CHAPTER XXIII

Boiler Fittings

CHAPTER XXIV

Boiler Auxiliaries

CHAPTER XXV

Reciprocating Steam Engines

CHAPTER XXVI

Valve Gears

CHAPTER XXVII

Condensers

CHAPTER XXVIII

Care and Running of Steam Engines

CHAPTER XXIX

Layout and Installation of Steam Plant

CHAPTER XXX

Engine Testing

CHAPTER XXXI

Selection and Erection of Engines

Part III.—Application

CHAPTER XXXII

Transmission of Power

CHAPTER XXXIII

Lubrication

CHAPTER XXXIV

Air Compressors and Pneumatic Tools

CHAPTER XXXV

Refrigerating Machinery

APPENDICES

LIST OF TABLES

LIST OF PLATES

MECHANICAL ENGINEERING

PART I.—WORKSHOP PRACTICE

CHAPTER I

METALS USED IN MECHANICAL ENGINEERING

1. *Ferrous Metals*

1. These include iron and steel in all their many varieties, the element iron forming the principal constituent of all of them, together with carbon, silicon, sulphur, and numerous other constituents, metallic and non-metallic.

2. **Pig iron** is the raw product of the blast furnace, in which the iron is extracted from its ores. From pig iron wrought iron is produced by purification process, and cast iron by melting and mixing in a cupola.

Pig iron contains about 3·5 per cent. to 4 per cent. of carbon as an essential constituent; also silicon, sulphur, phosphorus and manganese as impurities. Both combined and uncombined (or "*graphitic*") carbon are present in various proportions, causing the pig to vary from "*grey,*" through "*mottled,*" to "*white.*" Grey pig may contain only 0·3 per cent. combined carbon, while white pig contains combined carbon only. The greater the proportion of combined carbon, the harder and more brittle the iron. (*See also* Sec. **10**, para. 8.)

From 1 per cent. to 3 per cent. of *silicon* is usually present, and increases the fluidity. It tends to turn combined carbon into graphitic, but if it exceeds 5 per cent. it makes the iron very hard and brittle.

Sulphur has the opposite effect, *i.e.* it turns graphitic into combined carbon, and makes the iron hard and white; it also decreases its fluidity when molten.

Phosphorus increases fluidity, but decreases strength; useful for fine castings, up to 1 per cent.

Manganese increases the proportion of combined carbon, and helps to eliminate sulphur.

3. **Cast iron** is generally similar to pig iron, but the proportions of carbon are controlled in the foundry, both by mixing various grades of pig iron and scrap, and by control

of the temperature and rate of cooling. The total carbon content is usually reduced by the action of the cupola to about 3 per cent. to 3·5 per cent., and the combined carbon should not exceed 0·8 per cent. in the finished casting, or it will be too hard to machine. (*See also* Sec. **10**, para 8.)

Cast iron is harder than wrought iron, but brittle and weak in tension, and cannot be forged.

4. **Malleable cast iron** is cast iron produced from white pig in which the carbon content is reduced below 1 per cent. after casting, by an oxidizing process. (*See* Sec. **12**, para. 2.)

5. **Wrought iron** is a comparatively pure form of iron, containing from 0·1 per cent. to 0·25 per cent. of carbon, which is present entirely in the combined form, *i.e.* as carbide of iron. It also contains various impurities, phosphorus, sulphur, and silicon being the most important. At high temperatures wrought iron assumes a pasty condition and cannot be cast, but it is ductile at ordinary temperatures, and can be readily worked at red-heat and welded at white-heat. It resists corrosion better than steel. It is not hardened by heating and quenching.

Its ductility is seriously affected by excess of impurities. Carbon should not, as a rule, exceed 0·15 per cent., and the other non-metallic impurities together should not exceed 0·25 per cent.

0·25 per cent. of Phosphorus will make it **cold short.**
0·03 per cent. of Sulphur will make it **red short.**
0·35 per cent. of Silicon will make it **cold short.**

6. **Pure iron.**—Perfectly pure iron is not a commercial product, but iron containing only 0·16 per cent. of impurities is obtainable under the name of *ingot iron*. It is produced in a molten condition by a special open-hearth process and cast. It is ductile and easily welded, and it offers great resistance to corrosion.

7. **Steel** is a general term applied to alloys of iron and carbon, in which the carbon does not exceed 2·0 per cent., and is present almost entirely in the combined condition, while other elements are frequently present, in quantities greater than the carbon, as essential constituents. Manganese, silicon, phosphorus and sulphur are usually present as impurities.

Steel is produced by adding carbon to wrought iron or by the decarburization of cast iron.

As the carbon content increases, the *hardness* increases progressively and the *ductility* and *toughness* decrease. The

tensile strength also increases at first but reaches a maximum at 0·9 per cent. carbon.

A carbon content above 0·2 per cent. gives the steel the property of hardening when heated and then suddenly cooled.

8. **Mild steel or low-carbon steel** contains less than 0·25 per cent. of carbon, and a minimum of constituents other than iron. It has a granular or non-fibrous structure and being free from impurities in the form of slag, which often disfigure wrought iron, it can be machined to a better finish and will take a high polish. It rusts more readily than wrought iron. It can be forged and welded but not cast.

9. **Medium carbon steel** contains from 0·25 to 0·60 per cent. of carbon, and is harder and stronger than mild steel, but can be machined without difficulty in the unhardened state. It can be hardened by heating and quenching, but not to a high degree of hardness. Readily forged, welded with some difficulty, cast with difficulty.

10. **High-carbon steel or tool steel** contains from 0·60 per cent. to 1·6 per cent. of carbon, and is often graded into six " tempers " according to its carbon content (the term as used here having no connection with its use in connection with heat treatment).

Particulars of plain carbon steels are given in Table **A** on page 4.

11. **Other constituents of carbon steels.**—All the above grades of mild and carbon steel contain from 0·25 per cent. to 1·20 per cent. of manganese (the higher proportion being used for spring steels), which increases tenacity and elasticity, but in excess makes the steel difficult to machine ; also traces of phosphorus and sulphur, which are impurities and make the steel brittle if present in excess.

12. **Alloy steels.**—This term covers a great variety of steels which contain, in addition to carbon, manganese, and impurities as in the case of carbon steels, other metallic constituents in sufficient quantity to affect the properties of the steel to a noticeable extent. The proportion of carbon affects the susceptibility to heat treatment just as in the case of carbon steel, but the different alloys vary somewhat in characteristics in this respect. In general, these steels are stronger and harder than straight carbon steels of similar carbon content. The principal types are given in the following paragraphs.

13. **Nickel steel.**—Up to 5 per cent. nickel gives a steel of high tensile strength, suitable for machine parts. With 30 per cent. nickel, the steel has a marked resistance to corrosion by sea-water and is used for the armouring of

submarine cables. With 34·38 per cent. nickel, the alloy has a negligible coefficient of thermal expansion and is used in measuring instruments. It is known as *Invar.*

14. **Nickel chrome steel.**—Up to 3·50 per cent. nickel and 1·50 per cent. chromium. Higher tensile strength and toughness than nickel steel. Very sensitive to heat treatment. Suitable for parts subject to shocks.

TABLE A.—*Carbon content in cast iron, carbon steel and mild steel and their various uses*

Percentage of carbon	Known as	R.A.O.D. vocabulary		Uses
		Nomenclature	Identification colour	
0·20	Mild steel	Steel, mild	Red and blue.	Boiler plates.
0·25	do.	do.	do.	Axles, rolled sections, structural steel.
0·30	do.	do.	do.	Tyres.
0·5–0·6	Med. carbon steel.	Steel, spring	Brown	Plate springs.
0·7–0·8	do.	*Steel, tool, carbon,* No. 3 temper.	Blue and yellow.	Blacksmith's, Boilermaker's and miner's tools, cold chisels, shanks for tools *tipped* with high-speed steel, wood-working tools.
0·9–1·0	do.	No. 2 temper.	Yellow	General engineering tools, cutters, taps, reamers, drills and punches, shear blades.
1·0–1·2	High-carbon steel.	No. 1 temper.	Red and yellow.	Tools taking light or finishing cuts on all metal-working machines.
3–5	Cast iron	—	—	

15. **Cobalt steel.**—Up to 5 per cent. cobalt increases the tensile strength and toughness and is used for tools requiring keen cutting edges. 35 per cent. cobalt steel has high magnetic retentivity and is largely used for permanent magnets.

16. **Chromium steel.**—Contains 0·60 per cent. to 3 per cent. of chromium, which gives greater penetration of the

effect of heat treatment, together with great strength and toughness. Used for heat-treated forgings requiring great strength and toughness, also ball and roller bearings and races. 3 per cent. chromium steel is used for armour-piercing projectiles.

17. **Stainless steel.**—A special chromium steel, containing 11 per cent. to 14 per cent. of chromium, which is practically proof against corrosion under ordinary conditions. If the carbon content falls below 0·10 per cent. it is known as "rustless iron."

18. **Chrome-Vanadium steel.**—Contains 0·80 per cent. to 1·10 per cent. of chromium and 0·15 per cent. to 0·18 per cent. of vanadium. Very similar properties to nickel and nickel-chrome steels. With high carbon content it makes a good tool steel.

19. **Nitralloy.**—A special aluminium - chromium - steel alloy which can be case-hardened by the absorption of nitrogen (*see* Sec. **27**).

20. **Manganese steel** contains 11 per cent. to 14 per cent. of manganese. Without heat treatment it is a hard steel of little ductility or toughness, which cannot be softened by heating and slow cooling; if heated to 1050° C. and quenched in cold water, it becomes exceedingly tough and ductile, while remaining extremely hard. Its hardness, however, is of a peculiar nature, in that it can be easily marked with a file or chisel and gives a low Brinell reading, but is difficult to machine except with special tools, and is extremely resistant to wear. The hardness appears to be developed by the action of the tools or wearing surfaces. It is, therefore, much used for rails, especially at points. It is almost unique in combining the qualities of great toughness and great hardness. It is practically non-magnetic.

21. **High-speed tool steels.**—These are steels, which, after proper heat treatment, are extremely hard and retain their hardness at a red-heat, only softening at about 1200° C. They can therefore be used for much faster and deeper cuts than carbon tool steel. They actually cut best at a red-heat.

Their composition and heat treatment (*see* Sec. **27**) vary with different makes, but they usually contain from 8 per cent. to 19 per cent. of tungsten, together with about 5 per cent. of chromium, and smaller proportions of manganese and vanadium.

2. *Non-Ferrous Metals*

1. **Copper** is a soft ductile metal, which is obtainable commercially about 99·95 per cent. pure. It has a good resistance to corrosion. Cold-working (as in drawing into

wire) increases its hardness and tenacity considerably; it can be resoftened by annealing, which in the case of copper means heating red-hot and quenching. It is an excellent conductor of heat and electricity, and is largely used for electric cables and wires. For machine parts it is principally used as a constituent of brass and bronze.

Copper castings are normally porous and unsatisfactory, but sound castings can be produced by adding 1 per cent. of boron suboxide flux.

2. **Zinc** is a soft, weak metal, which can be cast or worked into sheets. Its tensile strength is greatly increased by rolling and annealing. It is ductile between 100° and 150° C., but brittle outside these limits. It has a good resistance to atmospheric corrosion at ordinary temperatures, the initial film of oxide forming a protective film, but can be burnt in air, and is readily attacked by acids.

The following three methods can be used for covering iron and steel with zinc as a protection against corrosion:—

(*a*) *Direct spraying* of zinc on the surface.

(*b*) *Galvanizing:* the plates or articles being dipped in molten zinc.

(*c*) *Sherardizing:* the articles being embedded in powdered zinc together with some oxide, and heated to 840° F.

3. **Tin** is a soft metal with a low melting-point and good resistance to corrosion, retaining a bright surface for a long time. It is chiefly used for coating other metals to protect them from oxidation, or as a constituent of alloys.

4. **Nickel** is a hard metal, which oxidizes superficially in the air, but corrodes very slowly.

Principally used for electro-plating and as a constituent of alloys (including nickel steel, *see* Sec. **1**, para. 13).

5. **Chromium** is an extremely hard metal, which is practically proof against atmospheric corrosion. It is principally used for electro-plating, and as a constituent of various alloy steels. (*See* Sec. **1**.)

6. **Aluminium** is the lightest metal commonly used for machine parts. It can be cast or cold-wrought, but having little strength in the former condition, is seldom used, so-called aluminium castings being usually alloys. Wrought into sheets, tubes, &c., it has many uses, and may have a tensile strength as high as 18 tons per sq. inch. It is soft and fairly ductile, and resists atmospheric corrosion very well, but is easily attacked by acids and alkalis. Mercury eats it away very rapidly by forming an amalgam, a very small quantity being sufficient to destroy a large aluminium vessel.

Aluminium is largely used in alloys.

7. **Lead** is a very heavy, soft and ductile metal, with a low melting point and good resistance to corrosion, though a film of oxide forms rapidly on exposure to air. The ease with which it can be worked renders it extremely useful for pipe and sheet work in building construction, but owing to its weakness it is little used in mechanical engineering, except in alloys, or occasionally for balancing purposes where weight is needed and strength is unimportant.

3. *Non-Ferrous Alloys*

1. The number of alloys available and their infinite variety of composition and properties, render it useless to attempt any detailed account of them. Only the main classes can be indicated.

2. **Brass** is an alloy of copper and zinc, containing over 50 per cent. of copper (66 per cent. being used for cast brass). Brass with a small proportion of copper is hard and brittle; with a large proportion of copper it is soft and ductile, if pure and well annealed.

Iron, tin or lead are frequently present up to 2 per cent.

Brass is suitable for castings and machines well.

Brass castings become very brittle when heated to dull red-heat.

3. **Bronze,** strictly speaking, is an alloy of copper and tin, but the term covers a great variety of alloys of copper with other metals, such as zinc, aluminium, manganese, &c. Phosphor-bronze contains copper (over 90 per cent.), tin, and a trace of phosphorus, and is a hard malleable alloy, which makes good intricate castings, machines easily, and resists corrosion well. Manganese bronze is really a brass containing 60 per cent. copper, to which a small quantity of manganese has been added. It can be forged and can be made stronger than mild steel, but is less ductile. Used for many machine parts, where mild steel would be liable to corrosion. Aluminium bronze contains 2·50 per cent. to 12 per cent. of aluminium, and is malleable and resists corrosion. Gun-metal contains copper, tin and zinc, and is similar to phosphor-bronze, but cannot be forged.

4. **Magnalium.**—A group of alloys of aluminium with small quantities of magnesium, copper, tin, nickel and lead. They are lighter, tougher and stronger than aluminium, and can be cast, forged, machined and welded.

5. **Duralumin.**—90 per cent. of aluminium with copper, manganese and magnesium. Can be hardened by suitable heat treatment. Can be forged and drawn, hot or cold. As strong as mild steel with one-third of the weight.

6. **Elektron.**—An alloy of magnesium (about 75 per cent.), aluminium, manganese, zinc and silicon. It is considerably lighter than aluminium and can be cast, forged, rolled and pressed.

7. **Aluminium-silicon alloys** are suitable for castings owing to their low contraction.

8. **Bearing metals.**—These may be brasses or bronzes, as described above, phosphor-bronze being a good example, or white metals containing tin, lead, antimony and copper in various proportions. The bronzes are hard and will wear well under heavy loads, while white metals bed themselves to the shaft better, cause less friction, do not wear the shaft so much as bronzes, and if they overheat, will melt superficially, and as a rule the shaft will escape damage. On the other hand they are more liable than bronze to fail, if at all tight or insufficiently lubricated. If the bearing becomes slack white metal is liable to fail through hammering. (*See also* Sec. **30.**)

9. **Solders.**—Easily fusible alloys used for joining metal surfaces by applying in a molten condition. There are three main groups :—

(*a*) *Brazing or spelter solder*, for use with brass, copper, iron and steel; contains copper, zinc, and sometimes nickel or tin.

(*b*) *Silver solders*, for use with silver, gold, copper and iron ; contains copper, silver and zinc.

(*c*) *Tin-lead solders*, for use with tin, lead, copper, brass, &c.; contains from 35 per cent. to 90 per cent. of lead alloyed with tin.

See Table **G**, page 84.

There are also solders for aluminium and other special purposes.

For Bibliography, see page 686.

CHAPTER II

MECHANICAL DRAWING

4. *Mechanical drawing and conventional signs*

1. Mechanical drawing.—Drawings required by the mechanical engineer may be either fully detailed and dimensioned for use in the workshop or may be merely illustrations showing the general effect the designer wishes to produce. The former type only will be considered in this volume.

The object of all dimensioned drawings is to put the designer's ideas clearly and accurately before the workman who has to turn these ideas into concrete forms.

Machine drawings will be used by the man at the bench, and must be simple. They should not contain a single superfluous line or dimension, but must, nevertheless, include all the information necessary to enable the workman to construct the work represented by the drawing.

All dimensions should, as far as possible, be clear of the drawing. It is essential that the number required, together with the material of which it is to be made, be written legibly against each separate detail, *e.g.* "6 *off*, *brass*". Details should be well spaced on a sheet and lettered A, B, &c. Standard size sheets should be used.

The scale should be clearly written on every sheet. If drawn full-sized, the fact should be stated. It should be clearly understood that dimensions must never be measured off a blue print. Such measurements, owing to the contraction of the paper during the printing process, will be quite inaccurate.

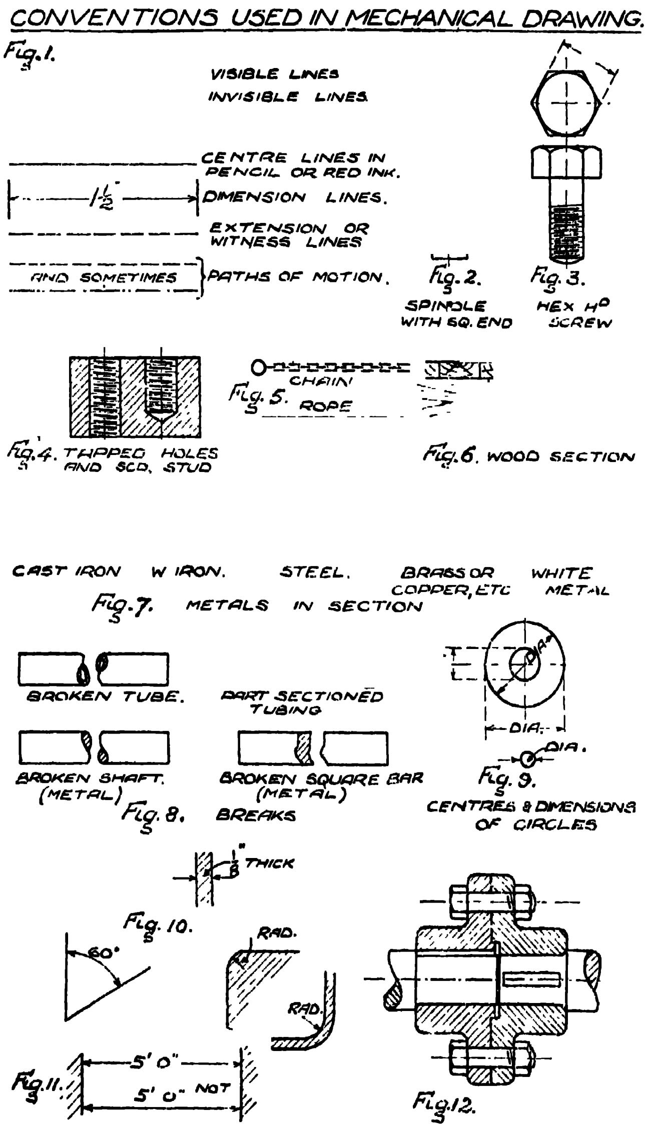
The date on which a drawing is completed should be written upon it, and any alterations made subsequently should likewise be dated.

All drawings should show by whom and on what date the dimensions were checked, together with the signature or initials of the draughtsman. It is thus possible to trace the responsibility for errors in drawings.

All drawings should be numbered to facilitate filing and reference.

Ornamental work, elaborate shading, &c. should be avoided. Clear bold lines should be employed, and the draughtsman must bear in mind that his original drawings will not be put into the hands of the workman. The latter

PLATE 1.


CONVENTIONS USED IN MECHANICAL DRAWING.
Fig. 1.
VISIBLE LINES
INVISIBLE LINES.
CENTRE LINES IN PENCIL OR RED INK.
1½"
DIMENSION LINES.
EXTENSION OR WITNESS LINES
AND SOMETIMES
PATHS OF MOTION.
Fig. 2.
SPINDLE WITH SQ. END
Fig. 3.
HEX HD SCREW
Fig. 4. TAPPED HOLES AND SCD. STUD
CHAIN
Fig. 5.
ROPE
Fig. 6. WOOD SECTION
CAST IRON
W IRON.
STEEL.
BRASS OR COPPER, ETC
WHITE METAL
Fig. 7. METALS IN SECTION
BROKEN TUBE.
PART SECTIONED TUBING
BROKEN SHAFT. (METAL)
BROKEN SQUARE BAR (METAL)
Fig. 8. BREAKS
DIA.
DIA.
DIA.
Fig. 9.
CENTRES & DIMENSIONS OF CIRCLES
1/8" THICK
Fig. 10.
60°
RAD.
RAD.
5' 0"
5' 0" NOT
Fig. 11.
Fig. 12.

will usually be supplied with a blue print reproduction from the draughtsman's original drawing. The original must, therefore, be clear so that a good tracing can be taken from it. When only a few prints are required pencil and paper tracing will be good enough.

2. **Conventional signs.**—Certain conventions are usually employed in machine drawing. Some of them are shown on Pl. **1**.

When several small dimensions are shown in line, the overall dimensions should be given as well; this saves time in checking. Fig. 1 shows the different forms of lines used to indicate different parts in a drawing. Figs. 2 to 6 and 8 are self-explanatory. Figs. 9 to 11 show the method of dimensioning small circles, thin plates, angles, curves, &c.

Fig. 7 shows a method of hatching sometimes employed together with a colour wash to illustrate different materials; this method should be adopted sparingly, as it may lead to confusion. A better method is to write legibly against each different part the name of the material of which it is constructed.

Fig. 12 shows the method of hatching to illustrate the section of a flange coupling for shafting.

3. **Limits.**—Limits should be marked for all dimensions which require to be accurately machined.

4. **Blue Prints.**—Blue prints can be bleached locally for alteration by treating with dilute soda solution applied with a brush. Alterations to the outline can be made by using this solution in the drawing pen. Blue prints on paper issued to the shops must be mounted or they will not last long. A satisfactory method is to mount the print on cardboard, sticking a blank sheet of paper on the back of the cardboard to prevent warping. The whole can then be varnished, preferably with clear cellulose, to avoid discolouring the print.

Blue prints can also be made on linen-backed paper.

For Bibliography, see page 686.

CHAPTER III

PRODUCTION OF CASTINGS

5. *Principles of design*

1. **Introductory.**—The economical production of serviceable castings is dependent on :—

i. A good design for the finished product.
ii. A pattern of suitable material and construction, made in such a way as to facilitate the work of the moulder.
iii. Careful moulding and casting.
iv. Correct composition of the metal or alloy most suitable for the finished article.

In the designing of a casting, it is not generally practicable to calculate its size from the stress which it has to bear. Correct proportioning is a matter of judgment and experience.

The various stresses set up by the contraction of molten metal on cooling, and the direction in which the iron crystals, on cooling, tend to set themselves, must be understood by the designer ; any design which is at all complicated should be the outcome of co-operation between the draughtsman, patternmaker, and moulder.

2. **Effects of crystallization.**—When molten metal solidifies in a mould it crystallizes out, and the crystals so arrange themselves that their longer axes are perpendicular to the surfaces of the casting.

For instance, in an angle casting, which has sharp corners, the crystals set themselves as shown on Pl. **2**, Fig. 1, and, consequently, lines of cleavage are formed at the corners, which must reduce the strength of the casting.

As far as the design permits, all corners must be rounded, as shown on Pl. **2**, Fig. 2, and it will be seen that no definite lines of cleavage are formed. *This is the first rule of design.*

In some cases this rule will affect not only the corners but the whole design, *e.g.* when hydraulic cylinders are made of cast iron, the casting will be as shown on Pl. **2**, Fig. 4 and not as shown in Fig. 3 ; in the latter case the end would be forced out.

3. **Effect of contraction.**—When a thick casting is made, the exterior solidifies first during the cooling process ; then the interior gradually solidifies and contracts, and its volume becomes insufficient to fill the already solidified envelope. This gives rise firstly to internal stresses, and then

to a drawing-away of the metal inside the envelope, so that jagged-sided cavities are formed, as shown on Pl. **2**, Fig. 5.

This *drawing* is inevitable where heavy masses of metal must be employed from considerations of strength or weight. In such cases, the remedy lies with the moulder (*see* Sec. **9**).

Drawing will also occur when a member of light section is cast with one of much heavier section, as shown on Pl. **2**, Fig. 6 ; in such a case, section B cools quicker than the more massive section A, causing a depression in the surface and a weak patch underneath at C.

In order to obviate drawing as much as possible :—

i. Keep the section of the casting constant.
ii. Avoid thick masses of metal.

These constitute *the second rule of design.*

If (i) cannot be done, make the change of section gradual, as in the pipe flange shown on Pl. **2**, Fig. 7. When (ii) cannot be done, the moulder must avoid draws by using a *feeding gate.*

The third rule of design is :—Either make sure that the members of a casting are correctly proportioned to obtain even rates of cooling and contraction, or ensure that free contraction, independent of other members, is possible.

For instance, a pulley wheel has its rim and boss united by the spokes. If the boss is designed too heavy and, therefore, cools after the other lighter components, any of the spokes may be drawn apart from the rim, as shown on Pl. **2**, Fig. 9. If the rim is too heavy in relation to the other members, the resistance of the previously contracted spokes may split the rim when it contracts, as shown on Pl. **2**, Fig. 8. In this case, the contraction of one member must bring stresses on the others, unless the contraction of all is simultaneous ; even though an actual parting of metal may not take place, severe strains will be set up which will weaken the casting and render it much more liable to fail unexpectedly.

It is for this reason that pulleys and flywheels are usually cast with curved spokes (Pl. **2**, Fig. 10), as these can give better than straight ones.

As close-grained grey cast-iron contracts less than white iron, the former should be specified for castings in which the members are not free to contract.

4. To sum up, the **three rules of design** are :—

Rule 1. Round all corners.
Rule 2. Keep the section constant.
Rule 3. Allow for free contraction.

5. The brass furnace can be used for small cast-iron articles up to about 100 lb. in weight, but the process is lengthy and wasteful of fuel.

In military establishments it will frequently be found economical to replace a light steel casting by one in copper alloy.

6. *Patternmakers' work*

1. **Introductory.**—A patternmaker must possess skill at working in wood and have a knowledge of machine drawing and design, foundry work, and machine-shop work. He must co-operate closely with the moulders, and will, therefore, usually work under the foundry foreman, although a large base workshop employing several such tradesmen would have a foreman patternmaker.

2. **Materials.**—Mahogany, yellow pine, and deal are the woods most commonly used in patternmaking, but any well-seasoned timber with suitable grain and hardness applicable to the work in hand can be utilized.

Mahogany is the best, as it has little tendency to warp or shrink ; it is easy to work and is hard enough to withstand wear ; but it is expensive, and its use is, therefore, restricted to small and intricate patterns and to those which are continually being used. Small portions of large patterns which have the most wear are sometimes edged with mahogany ; small detachable pieces are also made of it.

Yellow pine, while not so good as mahogany as regards warping and working, is cheaper, and should be employed for the majority of good patterns and core-boxes which are to be used a moderate number of times (say 100).

Deal is used for simple patterns and core-boxes from which only one or two moulds are required, and from which repeat castings at long intervals are not likely to be wanted. It warps and shrinks considerably in store, but is cheap.

Patterns used for repeat work, *e.g.* grenade castings, dug-out roof-beam supports, &c., are best made of white metal or brass, cast from wooden patterns and then machined under the supervision of a patternmaker. In this case, the original wooden pattern must be given a double contraction allowance, as there is contraction both in the casting of the pattern and of the final castings.

3. **Tools and equipment.**—Details of patternmakers' tools are given in Appendix III. Civil patternmakers provide their own hand tools.

With the hand tools enumerated in Appendix III, and given reasonable time, a good patternmaker will produce any ordinary pattern required in the service, but a lathe of some sort is essential if considerable output is required.

Where patternmakers are employed in the service, ae metal lathe will always be available, and a great deal of the

patternmakers' turning can be done on this, provided that the wood hand-turning tools (Appendix III, List C) are available.

In a pattern shop of large size, the following tools should be provided :—

A 6-inch centre wood lathe, capable of taking a 2-foot 6-inch diameter face-plate for dealing with such articles as pulleys.

A small band saw, for cutting quickly and roughly to size.

A wood trimmer.

A small circular saw.

4. **Setting out.**—A patternmaker should be provided either with a machine drawing of the article to be made or with the duplicate casting or part, which will usually be broken. Before starting to work, he makes a full-sized drawing of the pattern (not the casting) on a board, adding all necessary allowances. This is termed *setting out.*

The pattern itself will not be an exact reproduction of the drawing, which shows the shape of the machined and finished casting. The patternmaker has to *interpret* the drawing, *i.e.* to think out the shape and construction of the pattern, and, in so doing, he has to allow for contraction, machining, and withdrawal of the pattern.

5. **Contraction.**—As most metals contract on cooling, the mould, and hence the pattern, must be made larger than the finished casting by the amount of contraction which will take place.

Normal contraction figures are :—

Cast iron in bed-plates, frames, girders, &c. ..	1/120
Cast iron in pipes, cylinders, &c.	1/96
Brass	1/80
Gun metal	1/72
Copper	1/64
Steel	1/48
Aluminium	3/128

In practice, contraction allowance can be ignored, as a contraction rule which adds the allowance automatically is used for setting out.

The correct contraction scale for the particular metal being dealt with must, of course, be used.

The patternmaker must know the metal to be cast, and this information should be written on the machine drawing, together with the number of castings required.

6. **Allowance for machining.**—Where a machined surface is required on the finished article, additional metal must be allowed, to enable a roughing cut to remove the skin

and a finishing cut to be taken. The amounts normally allowed are :—

	Inch.
Cast iron or steel—	
External	1
For boring	$\frac{3}{16}$
Brass or copper alloy—	
External	$\frac{1}{16}$
For boring	$\frac{1}{8}$

For long thin castings, where warping may be unavoidable the machining allowance should be increased. The larger allowance in boring is to compensate for any displacement of the core. Each case must be considered on its merits, using the above figures as a guide.

Machined surfaces are usually shown on the drawing by a red line or a small letter, " f ". The pattern should be made in such a way that surfaces which require machining should be cast in the bottom of the mould, as any faults that may occur will be at the top of the mould.

7. **Withdrawal of pattern.**—To facilitate the withdrawal of a pattern from the mould, taper is given where vertical, cylindrical, or flat faces are used ; this taper varies from $\frac{1}{16}$ inch to $\frac{1}{4}$ inch per foot, depending on the depth of the face and the use to which the article is to be put.

7. *Principles of moulding that a patternmaker must know*

1. **Complete pattern in one box.**—(*Simple self-coring pattern.*)—A patternmaker must know the various processes and devices employed in the foundry.

A few examples of moulding methods will therefore be considered from a patternmaker's point of view. Details which concern the moulder alone are not given.

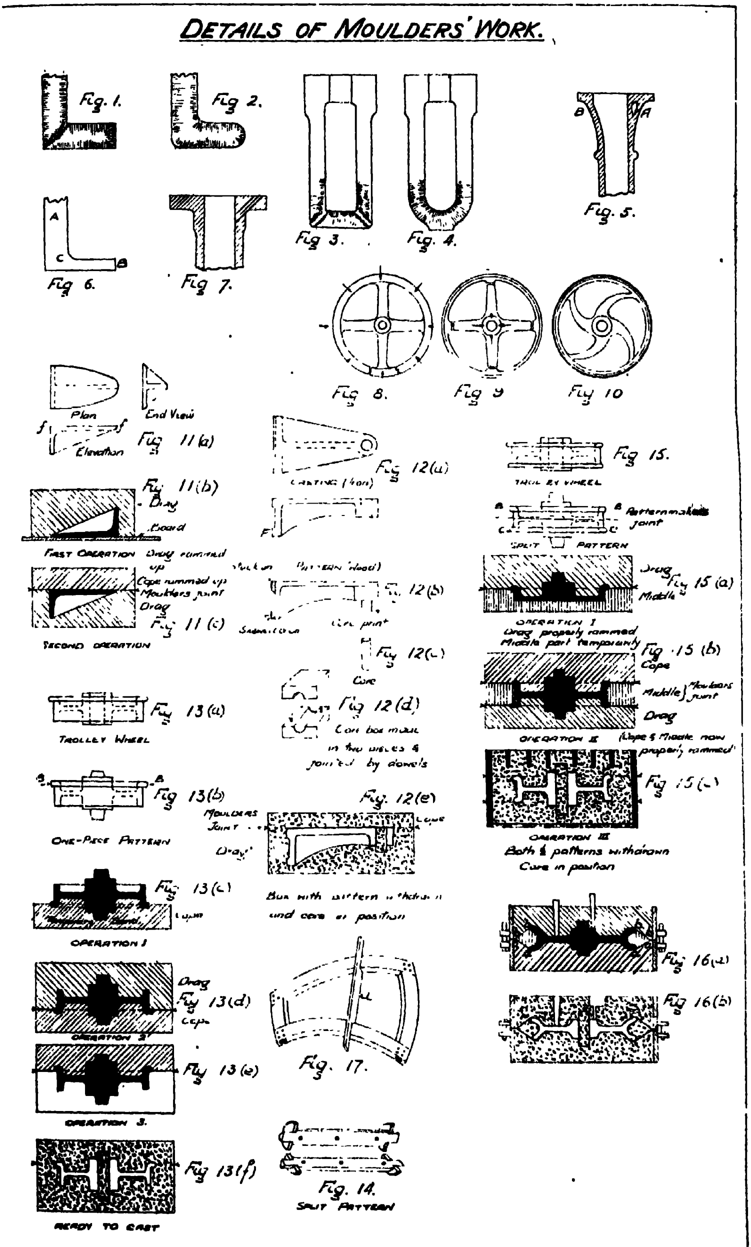
Pl. **2**, Fig. 11 (*a*) shows the casting of a bracket.

The pattern will be of exactly the same shape as the required casting (which has not to be machined), but slightly larger to allow for contraction.

The moulder takes his bottom moulding frame or drag (*see* Pl. **2**, Fig. 11 (*b*)) and places it upside down on a board. The face, *ff*, of the pattern is placed on the board inside the drag, and sand is rammed up round it. The drag is turned over, and parting sand is sprinkled over the surface. The cope, or top frame, is placed in position on the drag, filled with sand, and rammed ; then it is removed, and holes are made in it for the molten metal to be poured through (Pl. **2**, Fig. 11 (*c*)).

In this example, no part of the pattern projects into the sand in the top frame or cope, which simply forms a cover.

PLATE 2.


DETAILS OF MOULDERS' WORK.
Fig. 1.
Fig 2.
Fig 3.
Fig. 4.
Fig. 5.
Fig 6.
Fig 7.
Fig 8.
Fig 9
Fig 10
Plan
End View
Elevation
Fig 11(a)
Fig 11(b)
Drag
Board
First Operation Drag rammed up
Cope rammed up
Moulders joint
Drag
Fig 11(c)
Second Operation
Fig 12(a)
Fig 12(b)
Core print
Fig 12(c)
Core
Fig 12(d)
Core box made in two pieces & jointed by dowels
Fig 12(e)
Moulders Joint
Fig 13(a)
Trolley Wheel
Fig 13(b)
One-Piece Pattern
Fig 13(c)
Operation 1
Drag
Fig 13(d)
Cope
Operation 2
Fig 13(e)
Operation 3.
Fig 13(f)
Ready to Cast
Fig. 14.
Split Pattern
Fig 15.
Trolley Wheel
Patternmakers joint
Split Pattern
Drag
Fig 15(a)
Middle
Operation I
Drag properly rammed
Middle part temporarily
Fig 15(b)
Cope
Middle
Moulders joint
Drag
Operation II
(Cope & Middle now properly rammed)
Fig 15(c)
Operation III
Both ½ patterns withdrawn
Core in position
Fig 16(a)
Fig 16(b)
Box with pattern withdrawn and core in position
Fig. 17.

The pattern has now to be withdrawn. It is first tapped to loosen it, and then drawn out of the sand. Unless the sides of the pattern are tapered, portions of the sand will usually stick to them and damage the mould.

2. **Patterns requiring loose pieces and a core.**—Pl. **2**, Fig. 12 (*a*) shows a more complicated form of bracket in plan and elevation, and the pattern for it.

This casting cannot be treated like that in para. 1, as the projection, F, would tear away the sand above it.

The pattern, Pl. **2**, Fig. 12 (*b*), will, therefore, be provided with a loose piece skewered on. In the first operation (*see* para. 1), enough sand must be rammed up round the loose piece to keep it in position, and the skewer will then be drawn out. The main pattern will be withdrawn first, and then the loose piece, F, will be fished for and removed.

As a hole (for boring) is to be cast in the bracket end, the finished mould must be solid at that part. To represent the hole, a core, Pl. **2**, Fig. 12 (*c*), of correct size is made of baked sand or clay, suitably stiffened. The core-box, Pl. **2**, Fig. 12 (*d*), in which the moulder forms the core, is made of wood by the patternmaker.

A core-print forms part of the pattern, and in this the core is placed. The finished mould with core in position is shown on Pl. **2**, Fig. 12 (*e*).

The use of loose pieces should, if possible, be avoided.

3. **Moulding with pattern in two boxes, by turning over.**—In the examples given in paras. 1 and 2, no portion of the pattern has projected into the cope. Pl. **2**, Fig. 13 (*a*) shows a cast iron single-flanged trolley wheel.

The pattern is made solid, and has core-prints ; a core-box (not shown) forms part of the pattern. It will be seen that, in order that the pattern may draw, the moulder's joint must be through B (the major axial plane). Pl. **2**, Fig. 13 (*b*).

The moulding process is :—

Operation 1 ; the pattern is reversed and pressed into sand in the cope up to the line BB. Pl. **2**, Fig. 13 (*c*).

Operation 2 ; the drag is placed in position after the moulder's joint has been made and sprinkled with parting sand, and sand is rammed round the pattern in the drag. Pl. **2**, Fig. 13 (*d*).

Operation 3 ; the box is turned over, the cope is removed, its sand is emptied, the joint at the top of the drag is made and sprinkled with parting sand, and the cope is replaced and rammed up. Pl. **2**, Fig. 13 (*e*). The cope is then removed, the pattern is drawn from the drag, the core is placed in position, and the cope is replaced. Pl. **2**, Fig. 13 (*f*).

4. **Split patterns.**—Pl. 2, Fig. 14 shows the split pattern for a pipe casting. It is jointed by means of dowels and sockets. To mould, the socket half of the pattern is placed with its flat face on a board and is rammed up in the drag, which is then turned. The top half of the pattern is fitted in position, the moulder's joint is made, and sand is rammed into the cope. The cope is removed, and thus there is a half-pattern embedded in both cope and drag. These are removed separately, the core is inserted, the cope is replaced in the drag, and the mould is ready for casting.

Now it is obviously possible to cast the pipe with a solid (unsplit) pattern. It will, however, be less convenient for the moulder to handle, and will take him longer. On the other hand, the split pattern will take the patternmaker longer to produce than the solid one. In practice, if one pipe was required, and a wooden pattern adopted, the solid pattern would be used; if 50 pipes were wanted, the split pattern would be used. It depends on which method is the cheaper in the end.

5. **Moulding with pattern in three boxes.**—Pl. 2, Fig. 15 shows a double-flanged trolley wheel and its pattern, which is split symmetrically. In this case, a three-part box with a middle part will be required by the moulder, and the middle part's height must be equal to the distance between the moulder's two joints, BB and CC.

The first operation is similar to that of the example given in para. 3, except that one half-pattern only is employed. Pl. 2, Fig. 15 (*a*).

In the second operation the cope and middle part are rammed up. Pl. 2, Fig. 15 (*b*). The method of drawing the patterns is obvious, and the third operation shows the core inserted. Pl. 2, Fig. 15 (*c*).

6. **False-core method.**—The double-flanged trolley wheel can be moulded in two boxes with a pattern similar to that used in the example given in para. 4 (split down the middle).

One half of the pattern is moulded in the bottom box in the usual way, the sand down to *aa*, Pl. 2, Fig. 16 (*a*), is removed as shown, and the whole surface is sprinkled with parting sand. The other half-pattern is then put in position, and sand is rammed in to form the second parting which slopes down to form the widest part, *bb*, of the top flange. Parting sand is sprinkled on surface *bb*; the cope is put on and rammed up.

By taking off the top box, the upper half-pattern can be removed. By replacing the top box, turning the mould upside down, and removing the bottom box, the bottom half-pattern can be removed.

G-10367

7. Strickling and striking-up.—The patternmaker must also know the principles of strickling, striking-up, loam moulding, and plate moulding, described in Sec. 9. Pl. 2, Fig. 17 shows a skeleton pattern for a solid panel, which is obviously much cheaper to make than a solid one. The sand between the frame members is removed by means of the shaped board, *a*, known as a *strickle*.

The making of the strickle is the work of the patternmaker. Pl. 3, Fig. 1 shows a strickle for reducing the depth of gear teeth in the sand, so that a casting smaller than the existing pattern may be produced.

Pl. 3, Fig. 2 shows the pattern (or the core) of a curved pipe being strickled up, the bent iron bar serving as a template. Two such half-pipe or core patterns are made and cemented together by the moulder. If flanges and core-prints are required, they can be fixed by the patternmaker in co-operation with the moulder.

Pl. 3, Fig. 3 shows a striking board, which is also made by the patternmaker for the moulder's use in striking-up circular patterns or cores in loam.

The proper grasping of patternmaking problems is a matter of experience, and their solution must generally be left to the patternmaker and moulder.

Only the simplest cases have been dealt with, but all the main principles have been embraced.

8. *Patternmakers' details*

1. Constructional joints, &c.—Owing to changing atmospheric conditions, articles of timber frequently warp, shrink or swell.

The aim of the patternmaker should be to construct patterns capable of resisting the dampness of the foundry sand and the heat of the pattern store, and strong enough to resist rough usage and the fair wear and tear of repeated use.

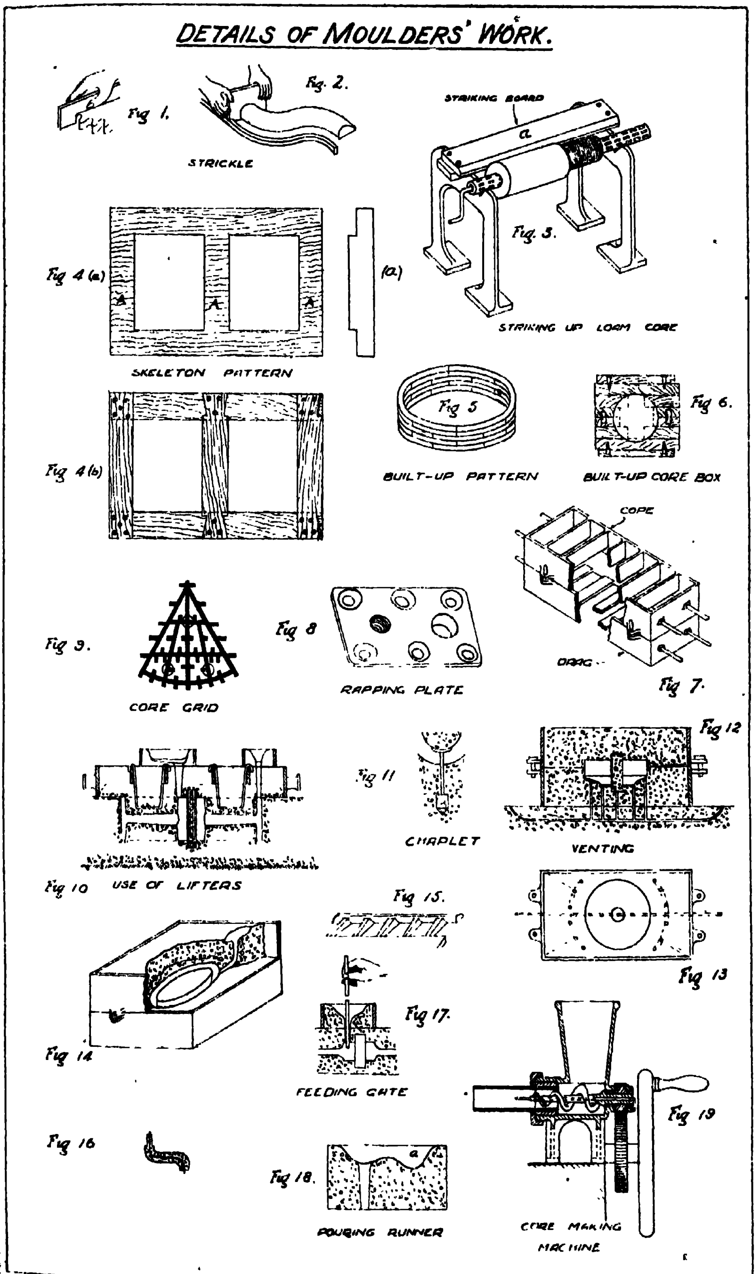
Timber is stronger with the grain than across the grain and this must be borne in mind throughout.

For instance, the frame, Pl. 3, Fig. 4 (*a*), if cut from the solid will have no permanence of form. The side members, AAA, have not the grain in the direction of their length. The built-up frame, Pl. 3, Fig. 4 (*b*), is strong, permanent in form, and built on correct lines.

In curved work, where considerable distortion will occur owing to shrinkage, it is the practice to *build-up* with a number of small curved sections, in which the grain runs differently in contiguous sections.

Pl. 3, Fig. 5 shows a built-up pattern, and Pl. 3, Fig. 6 a core-box.

PLATE 3.


DETAILS OF MOULDERS' WORK.
Fig 1.
Fig. 2.
STRICKLE
STRIKING BOARD
a
Fig. 3.
STRIKING UP LOAM CORE
Fig 4 (a)
A
A
A
(a)
SKELETON PATTERN
Fig 4 (b)
Fig 5
BUILT-UP PATTERN
Fig 6.
BUILT-UP CORE BOX
COPE
DRAG
Fig 7.
Fig 8
RAPPING PLATE
Fig 9.
CORE GRID
Fig 10
USE OF LIFTERS
Fig 11
CHAPLET
Fig 12
VENTING
Fig 13
Fig 14
Fig 15.
Fig 16
Fig 17.
FEEDING GATE
Fig 18.
a
POURING RUNNER
Fig 19
CORE MAKING MACHINE

2. **Finishing patterns.**—Varnishing of patterns should be completed before they go to the foundry, to protect them from the damp of the moulds.

Two coats of shellac varnish (shellac in methylated spirits) are usually given to those for important work.

Some such simple expedient as marking core-prints red, and the rest of the exterior of the pattern black, is generally adopted to help the moulder.

3. **Storing patterns.**—Patterns should be stored in cool, dry, well-ventilated rooms fitted with shelves. A set of patterns for one job may involve several pieces ; thus, a plummer block and bearing will have top, bottom, bushes, loose pieces, core-boxes, &c., and all these should be tied together and labelled.

A pattern register should be kept, showing clearly the job for which each set was made and the number and nature of the separate articles in each set, so as to avoid losses. If this is done methodically, much time will be saved, especially in large shops.

4. **Altering patterns.**—It will often happen that a job is received in a shop for casting, and that patterns nearly the same as those required are available in store. The rule should be to make additions only to existing patterns in order to adapt them ; never cut into an existing pattern unless it is absolutely certain it will never be required again, as patterns are expensive to produce.

9. *Moulders' work*

1. **Tools, equipment, and stores.**—Moulders in different parts of Great Britain call the same tools by different names. The personal tools of a moulder are given in Appendix IV.

2. **Types of iron moulding.**—Iron moulding comprises three distinct branches, viz. :—

i. Green sand.
ii. Dry sand.
iii. Loam.

In addition to these, there is chill casting.

Green sand does not refer to the colour of the sand, but means that the metal is cast in a damp mould. This is the normal practice with iron.

Dry-sand moulding implies that the mould is dried thoroughly before metal is run into it, and is employed where a fine surface is required and also for heavy and expensive jobs.

Loam moulding does not require a pattern in the ordinary sense; strickles and sweep boards are used with wet loam, straw, &c. It is confined to symmetrical articles.

Chill casting is the process of casting metal in metal moulds; the quick-cooling action causes an intensely hard surface to be formed on the casting.

3. Foundry sands.—In green-sand moulding, the sand of which the moulds are made must be fine-grained, free from lumps, and of such a consistency that it holds together when damp. It must be infusible when in contact with molten metal, and the mould must be sufficiently porous to allow the gases formed by the metal in the mould to escape.

The most suitable mixtures obtainable from sands in any locality are obtained only after much experimenting; the military engineer must follow local practice. A casting can be produced, however, in almost any type of yellow-coloured sand which will hold together when damp and retain the shape of the pattern. If such sand cannot be found, the addition of a little clay will improve the adhesive properties of otherwise suitable sands which may be available.

Sea sand is not suitable.

A practical test for quality of sand is to pour some molten metal through a pouring runner and a sprue into an open mould. If the metal lies quiet, or does not blow or bubble more than three times it is suitable for use. The thickness of the metal layer need not be more than one inch.

A foundry floor is covered with sand to a depth of from two to three feet. It is used repeatedly for filling moulds; its black colour is caused by the coal dust with which the facing sand is mixed. Floor (or backing) sand constitutes the body of the mould, but the actual surfaces which come in contact with molten metal are made of facing sand.

Facing sand is the true moulding material; its composition and consistency is varied by the moulder to suit the work in hand. For large castings, the weight of molten metal necessitates a *strong* sand which has good binding power and which will not crumble away. Smaller castings are better made in sand which has less binding power, and which, in consequence, is more porous and, therefore, better adapted for carrying off the gases formed in the mould on casting.

The moulder is responsible that his mixture of facing sand is of the right consistency. A rough recipe for general small work in iron is six parts floor sand, four parts new sand, and one part coal dust.

The ingredients are ground up in a sand-mixing machine, or they may be mixed by hand where necessary. Coal dust is used to prevent the sand in contact with molten metal from being fused, and thereby making the surface of the casting rough, *i.e.* sand-burnt.

When heated by the molten metal, the coal dust produces gas which forms a cushion between the sand (which is fusible

to a certain extent) and the molten metal. Excess of coal dust prevents light castings from running sharply and may result in "*cold shuts*" (that is, failure of two bodies of molten metal to run together).

Parting sand is the material used to prevent any required portions of a mould from adhering. It usually consists of baked red sand, brick dust or burnt sand from the fettling shop. A thin layer is sprinkled on the surface of the mould wherever a joint is required between the respective parts. Parting sand must be dry.

4. **Green-sand moulding** can be subdivided into :—

i. Turning over.
ii. Bedding in.
iii. Moulding in open sand.

Moulding by turning over is performed in boxes (or flasks), which are described in Sec. **7**.

The bottom box or drag has cross bars, as shown on Pl. **3**, Fig. 7, to retain the sand. The top box or cope has ribs for the same purpose, so placed as to facilitate ramming the sand ; the ribs do not extend far enough to foul the pattern. Projecting pins on the drag register with holes in the lugs of the cope.

Small boxes have no cross bars or ribs.

Moulding boxes are made of cast iron, with the sides left rough to facilitate adhesion, or of wood.

5. **Details of moulding by turning over**.—The moulding of the flanged pipe, Pl. **2**, Fig. 14, will now be considered from the point of view of the moulder.

Operation 1.—The portion of the pattern carrying the dowel sockets is placed face downwards on the turn-over board inside the drag, which is supported on its face edge on the board. Damp facing sand is rammed round the pattern so as to cover it for about 1½ inches ; the remainder of the mould is then rammed up with floor sand which has been previously riddled, and the bottom surface of the drag is smoothed off with a board.

A blunt vent wire is inserted in the sand in a large number of places. The object of this is to allow outlets for the gases formed in casting ; it is known as venting.

Operation 2.—The drag is turned over so that the half-pattern comes on top. The top half of the pattern is fitted to the bottom half, and parting sand is sprinkled lightly over the surface of the mould. The cope is placed in position on the drag. The runner stick (if used) is placed in a vertical position, clear of the mould, where the pouring gate is required, and pushed about half an inch into the drag to mark the

position of the sprue. The top half of the pattern is covered with facing sand and the mould is completed with floor sand as in operation 1, riser sticks being inserted over each flange; the top surface in the cope is levelled off with a board, and vented as above. Alternatively, the pouring gate may be cut with a brass tube of the required size after the mould has been completed. Sometimes in the case of small castings, the moulder will withdraw the pattern before selecting the position for the pouring gate.

Operation 3.—The runner stick and riser sticks (if any) are gently tapped and removed. The cope is then removed, turned over and placed, pattern upwards, alongside the drag. Before the pattern is removed, the edges of facing sand next to the pattern are swabbed lightly with a sponge or wet brush, to ensure that they will not break away on the pattern being withdrawn.

In drawing the pattern, care must be taken that it is lifted vertically, and that none of the sand comes away with it. The moulder first loosens the pattern by inserting the point of an iron pin in the wood, and by tapping the latter all round so as to give the pattern a little clearance sideways; he then lifts it clear by the dowels, or by a spike inserted into a hole, if one has been made in the pattern for that purpose. (Large patterns have special rapping and withdrawing plates fitted (*see* Pl. 3, Fig. 8), the withdrawal being carried out by means of rods screwed in the tapping plate.)

Operation 4.—By means of a trowel, the moulder now cuts a channel from the down runner to the edge of the mould. He has probably damaged the edges of the mould in drawing the half-patterns. These must be trued up, and the sand in the bottom of the moulds blown away with hand bellows.

Operation 5.—The surface of the mould has now to be coated with plumbago, by sifting through a muslin bag. This is to ensure that the molten metal does not come into contact with the sand, which it would partly fuse. In this respect the plumbago helps the coal dust in facing sand, which alone is not sufficient to produce the desired result.

The core, made as described in para. 13, and painted with *blackwash* (*i.e.* a mixture of plumbago and water), is inserted in position, supported by the impressions left by the core-prints.

Operation 6.—Preparing the mould for being cast. The cope is placed on the drag. The runner stick and riser sticks (if any) are temporarily replaced and the pouring and riser bushes lined with sand and bell-mouthed, after which the sticks are removed. The object of these bushes is to obtain sufficient pressure of metal to ensure that all cavities in the

top of the mould are filled up, and to intimate when the mould is full. They would not be fitted for shallow castings when extra pressure is not required, the metal being poured direct into the hole left by the runner-stick.

In this case the pouring cup should be made as shown on Pl. **3**, Fig. 18. A depression is made at "a" so that metal will not flow down the runner until the depression has been filled, by which time, the man using the ladle can ensure a steady flow.

When the metal is poured into the mould, it tends to float the cope and force it off the drag. To prevent this, either weights must be laid on the cope or it must be joined to the drag by cotters through the pins.

The mould is now ready for the operation of casting, which if dealt with in Sec. **10**.

6. **Use of lifters, nails, and sprigs.**—The example given in para. 5 is of the simplest nature, and is intended for comparatively small castings only.

With bigger and more complicated patterns, the weight of unsupported sand in the cope would be too great, and recourse is had to lifters, which are pieces of round iron, bent and hooked on to the bars of the cope, as shown on Pl. **3**, Fig. 10.

With still larger moulds, grids (*see* Pl. **3**, Fig. 9) are cast and hung from the bars of the cope for the same purpose.

In all work where there are small isolated bodies of sand, and narrow weak edges, projections, &c., cut nails, from ½ inch to 6 inches in length and known as sprigs, are inserted at the time of moulding, and also after the pattern has been withdrawn. Should the mould crack or show signs of giving way, nails are thrust in to strengthen it and to prevent the sand from being washed away by the rush of the metal.

7. **Chaplets.**—These are used to support long or bent cores, where the print is insufficient to hold them firmly. Pl. **3**, Fig. 11 and Pl. **4**, Fig. 13 (*a*) show the method of using them. A small footing of wood or iron is placed under the chaplet in the case of large work.

For pipes 6 feet long or over, additional chaplets should be placed on the top, to prevent the core from lifting.

Chaplets should be made of non-rusting material, and be tinned all over before insertion. Rust would cause blowholes.

8. **Venting.**—There is always a free escape for gas from the top of the cope. The drag, however, rests on a sand bed, and gas coming through vent-holes finishing on the bottom of the drag must have a clear path through the sand floor. This is effected by venting the floor, as shown on Pl. **3**, Fig. 12, or by making grooves in the bed.

There is also an avenue for the escape of gas between the drag and cope. A channel is therefore made round the pattern on the surface of the sand in the drag, and thence to the edges (*see* Pl. **3**, Fig. 13) ; a curved vent iron is inserted in the groove, so as to get underneath the pattern. This, of course, must be done with the pattern in position, and is especially important when the bedding-in process is employed.

9. **Runners, risers, &c.**—Pouring-runners should conform to the following :—

i. Their number, size, and position must be such that all portions of the mould can be filled with metal while it is still thoroughly fluid.
ii. Their position must be such that the entering metal does not immediately come into contact with sharp edges of the mould, thereby washing them away.
iii. Their size and position must be such that drawing cannot occur at the points where they join on to the mould.
iv. Their position must be such that the pouring cup can be kept full, otherwise slag, which normally floats to the top, will find its way into the mould.

If metal is poured from the top direct into a deep mould, it will immediately begin to cool in the bottom of the mould ; but as long as sufficiently hot and fluid metal continues to be poured in, a satisfactory casting should result.

If the pouring gate supplies two or more channels which divide and reunite at the opposite side of a long pattern, as in Pl. **3**, Fig. 14, a cold shut may result at the junction if the metal has cooled and become insufficiently fluid to unite. If the runner cannot be made large enough to ensure a rapid flow of metal, two or more runners should be provided and the metal poured into both simultaneously.

On Pl. **4**, Figs. 11 and 12, if the runners were placed to deliver directly to a flange, the metal would tend to wash away the sharp corners and to fall direct on to the hard core, a steady flow of metal in the mould would not be maintained, and the pouring cup would tend to empty too quickly.

A horizontal runner is, therefore, provided, which is fed by the pouring-runner, the metal entering at the side.

The pouring-runner for a pulley would be placed over the boss, which is the heaviest portion, so that the runner could be made big enough and a draw avoided. If it were placed at the flange, and were of sufficient size to fill the mould quickly enough, it would be so much heavier than the section of the rim that a draw would occur.

In cases where the size of the pouring-runner is so limited, several small branches may be taken from the main channel to various places in the mould (*see* Pl. **3**, Fig. 15).

A *riser* is a vertical opening situated either at the highest point of the mould or opposite the pouring-gate, and its chief object is to show when the mould is full of molten metal. It also allows air and gas to escape while the metal is being poured and, further, it helps to prevent *drawing*. It is sometimes necessary to cover the riser with a piece of paper and a ball of sand to prevent air from being sucked in.

10. **Feeding-gates.**—Feeding-gates are sometimes required in addition to ordinary runners and risers (*see* Pl. **3**, Fig. 17).

Their object is to feed with molten metal under pressure those places which are most liable to draw. Where the additional head of metal is not sufficient to effect this, a wrought iron rod is inserted through the feeding-gate and given an up-and-down movement in the molten metal.

The effect is to preserve a passage to the inside of the boss until its outside surface actually sets, so that shrinkage can be made up by metal under pressure in the riser.

11. **Bedding-in.**—In the process of green-sand moulding, called *bedding-in*, a drag is dispensed with, the cope being pegged down to correct register. It is useful in the case of big castings for which suitable boxes do not exist. The sand is dug up and loosened to a sufficient depth, and into it the pattern is beaten with mallets, care being taken that it is kept level. As soon as a rough impression of the mould is obtained, from one inch to two inches of facing sand is riddled over the whole area, and the pattern is beaten down again. It requires skill to bed it evenly.

The face is then strewn with parting sand, and the cope is put in, set with stakes, and rammed, &c. The bottom half is vented. Venting is facilitated if the whole mould is in a cinder bed.

12. **Uses of open-sand moulding.**—The process of moulding in green sand by bedding-in without a cope has a very limited application. The top of the mould is uncovered and the top face of the casting must, therefore, be horizontal; castings are irregular and porous because they are not cast under pressure and because their surfaces set before all hot gases have been expelled.

Castings made in open sand are, therefore, only employed for very rough work, such as moulding-boxes, back-plates, core-plates, and rough weights.

13. **Cores.**—Cores are used in a mould to prevent molten metal from flowing into places required to be hollow in the

finished casting. They may be of any required shape, and are usually made in core-boxes, Pl. **2**, Fig. 12 (*d*), by ramming up. For repeat work they are made in core machines (*see* Pl. **3**, Fig. 19).

The same conditions must exist in cores as in the moulds themselves. The substance of cores must be stiffened with rods, grids, or nails. Vents of sufficient area must be provided to carry off gas and air, and the cores must be secured against the pressure of liquid metal.

A good composition for small cores, such as those shown on Pl. **2**, Fig. 12 (*c*) and Pl. **3**, Fig. 16, is two parts yellow sand, two parts floor sand, and one part horse manure. Cores are rammed up damp, clay-water being used, if necessary, to give the required cohesion. They are then baked in a core-oven.

A good design of a core-oven is shown on Pl. **6**, Fig. 3. For field use a coke brazier, supplying heat to a sheet-metal drying chamber in which the cores are placed, is quite effective.

The baking process will tend to make the cores brittle; cores are, therefore, reinforced with iron wire of varying size; this is necessary in all but the smallest cores (those less than 4 inches long).

Reinforcement of cores of complicated shape is difficult, so binders or core-gums are mixed with the sand, &c. instead of water. Linseed oil is a good binder.

Venting is effected by stabbing straight cores, before heating, with one or two venting wires down the middle; this forms a duct through which the gases from the porous core can escape into the air.

Bent cores are rammed up in halves, a waxed string is inserted (*see* Pl. **3**, Fig. 16), and the two portions in their half-boxes are stuck together with clay-water. After baking, it will be found that the string is either burnt or can be easily removed. Cores are painted with blackwash of plumbago and water after baking.

14. **Dry-sand moulding.**—This is used for heavy work and that which is wanted specially sound and free from blow-holes. The mould is made in exactly the same way as in the green-sand method, but the sand mixture is different, containing manure or sawdust, which burns when baked, leaving venting passages.

The sand mixture for small work can be 2 parts floor sand, 2 parts new yellow sand, and 1 part dung or sawdust.

The whole mould is baked in the same way as a core, and then it is painted, while hot, with blackwash consisting of clay-water and plumbago. Venting must be provided for.

15. **Plate and machine moulding.**—These two methods can be carried out in green sand or dry sand; and, being

adaptable to repeat work, result in a great increase of output by each moulder.

In *plate moulding* the pattern can be divided into two portions, one on either side of a pattern-plate made of wood or metal, Pl. **4**, Fig. 1.

The pattern-plate, provided with drilled lugs which register with those on the cope and the pins on the drag, is placed between the cope and the drag, the surface is sprinkled with parting sand, and then both the cope and the drag are rammed up on to the plate.

The cope is turned, the plate is removed, plumbago is sprinkled on the mould, and the cope is replaced. Thus the number of operations has been greatly reduced.

The design of runners requires experience.

Rapid moulding as above will use up a large number of boxes. Therefore, recourse is had to split boxes, which are removed from the moulds on their arrival in position on the casting floor, and used repeatedly.

When withdrawing the cope from the plate, and the plate from the drag, great steadiness is required to avoid breaking the edges.

Moulding machines, Pl. **4**, Fig. 2, are worked on the same principle, except that two plates are used (usually on separate machines). Hand-ramming is used round the patterns; but the sand for box filling is pressed in by a lever, *a*, and a board, *b*, and the patterns and mould are separated by a straight mechanical movement or, in some cases, by means of a hydraulic ram, *c*.

As a further preventive against damage to the edges of the mould, on the best machines the pattern-plate is withdrawn through a stripping-plate, Pl. **4**, Fig. 3, which can be turned with the mould.

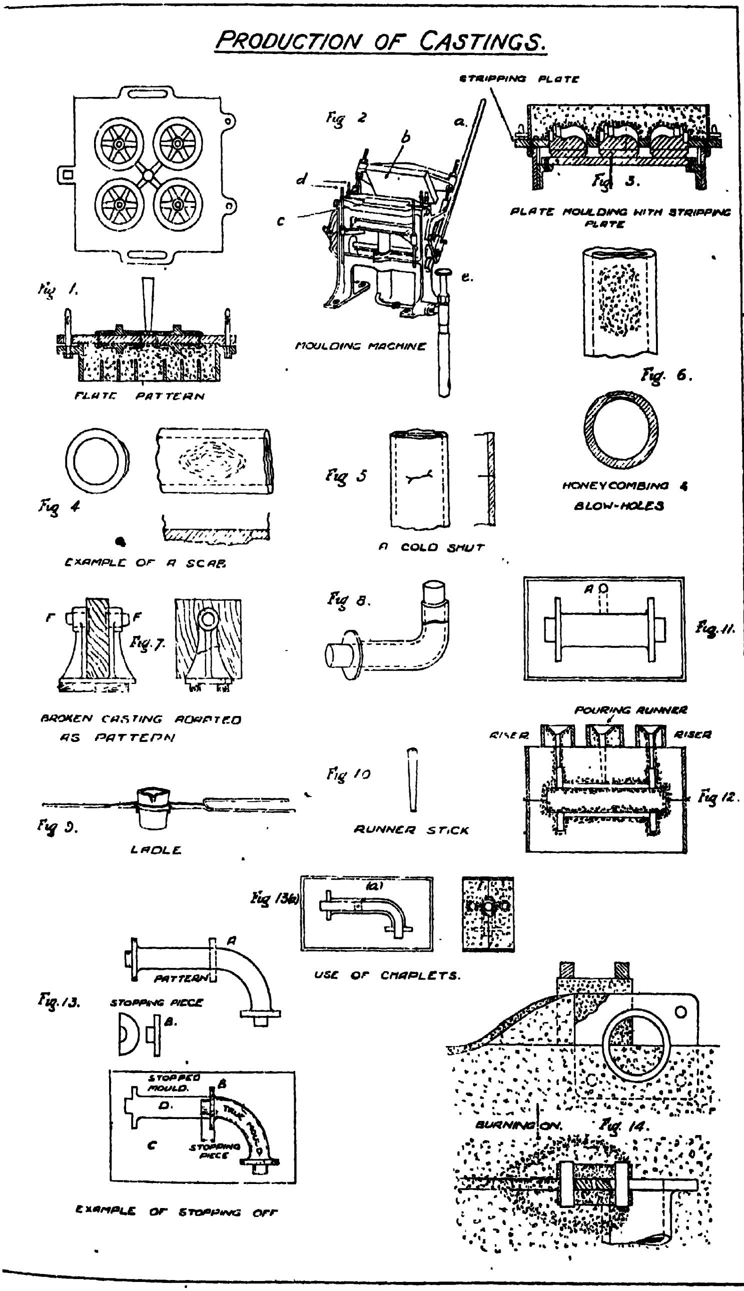
On Pl. **4**, Fig. 2, the pattern-plate is placed, pattern upwards, on *c*, and the stripping-plate and mould are supported on the rods *dd*. To draw the pattern, the hydraulic pedal is pressed, and the stripping-plates and mould are withdrawn from the pattern-plate without jerking.

Where these machines are installed, a core-making machine, Pl. **3**, Fig. 19, is usually required to keep pace with the moulding.

16. **Loam moulding** will not often be practised by the military engineer, but, where one or two castings of a symmetrical nature are required, loam patterns, made by the moulder himself and moulded in green sand, can be used instead of expensive wooden patterns.

This process is especially suitable for pipe-work. The core is first formed on a core bar made of perforated pipe, which is supported on trestles. A hay-band covering is first wrapped

PLATE 4.


PRODUCTION OF CASTINGS.
Fig 1.
PLATE PATTERN
Fig 2
a.
b
c
d
e.
MOULDING MACHINE
STRIPPING PLATE
Fig 3.
PLATE MOULDING WITH STRIPPING PLATE
Fig. 6.
HONEYCOMBING & BLOW-HOLES
Fig 4
EXAMPLE OF A SCAB
Fig 5
A COLD SHUT
F
F
Fig. 7.
BROKEN CASTING ADAPTED AS PATTERN
Fig 8.
A
Fig. 11.
POURING RUNNER
RISER
RISER
Fig 12.
Fig 10
RUNNER STICK
Fig 9.
LADLE
Fig 13(a)
(a)
USE OF CHAPLETS.
A
PATTERN
Fig. 13.
STOPPING PIECE
B.
STOPPED MOULD.
B
D.
C
STOPPING PIECE
EXAMPLE OF STOPPING OFF
BURNING ON.
Fig 14.

tightly round the bar and, over this, a coating of loam is applied as the bar is revolved.

A good composition for loam cores is yellow sand mixed with clay-water containing one-fifth of its volume of horse dung and cow hair. Loam is added until the board, *a* on Pl. **3**, Fig. 3, set to the correct distance, trues up the edge of the revolving core. The core is dried in the stove (it will be seen that the ends of the core-pipe form the core-prints), and is then given a coat of blackwash.

To make the pattern itself, the core, after baking, is put back on the trestles, and another layer of loam is added to the required thickness of the pipe. The whole is baked, and any flanges required are made by the patternmaker and fixed by nails to the loam pattern.

The pattern is then moulded in the usual way, the thickness-piece is peeled off (the blackwash forming the parting), and the core is placed in position.

Bent-pipe patterns can be made in a similar way in loam by the strickle, Pl. **3**, Fig. 2. The core and pattern are made in halves and stuck together by the moulder with blackwash.

17. Faults to look for when inspecting castings.—A good specification for castings states :—

The castings shall be clean and sound, both externally and internally. They shall be free from honeycombing, blow-holes, scabs, cold shuts, draws, and other defects.

No stopping-up or plugging shall be permitted. No casting shall be made in open sand. Cores shall be cast-in accurately.

The metal shall be re-melted once in the cupola, and free from admixture of inferior material. It shall be uniformly tough and close-grained. It shall be of such strength that a turned bar having an area of 2 *square inches shall bear a tensile strain of not less than* 16,000 *lb. per square inch. A test bar,* 2 *inches deep by* 1 *inch thick, placed on supports* 3 *feet wide, shall bear a cross-breaking strain of not less than* 28 *cwt., with a deflection of not less than* $\frac{3}{8}$ *inch before breaking.*

Drawing.—The fault termed *drawing* has been dealt with in Sec. **5**, para. 3. Its presence can be detected by a depression in the surface, and if it occurs at a point where strength is required, the casting should be condemned.

Honeycombing and blow-holes are caused by insufficient venting, and by lack of head. Honeycombing, or sponginess, consists of a large number of small holes on the surface, Pl. **4**, Fig. 6, which probably lead into large blow-holes in the interior. Honeycombing and blow-holes will usually appear at the top of a casting, where the pressure is least. If honeycombing is of any depth, the casting should be rejected. In any case, pins should be inserted to ascertain if honeycombing extends to blow-holes.

Honeycombed surfaces can be worked-up with a hammer ; the inspecting officer should, therefore, look for hammer marks

at the top of a casting, and tap it hard all round with a hammer to ascertain if hollows exist behind a thin film of metal.

It is better not to pass work in which honeycombing and blow-holes occur, even if they are found in portions of the casting not subjected to load, as their existence indicates that the casting may be also blown in a more vital part.

Scabbing, Pl. **4**, Fig. 4, may occur on all parts of a casting. It is caused by the washing away of sand, due to weak sand, hard ramming, or bad venting.

Its presence indicates that sand is embedded somewhere in the casting, and this should be sufficient for it to be condemned. The roughened surface can be chipped off with a chisel, &c.; this surface can, however, be seen by the inspecting officer.

Cold shuts, Pl. **4**, Fig. 5, occur when two streams of metal, which are not hot enough to unite properly, meet in a mould.

In such cases, the casting is practically fractured, and should be condemned.

18. **Miscellaneous economies.**—It is often possible to cast direct from a broken casting, thereby avoiding the expense of a pattern.

Pl. **4**, Fig. 7 shows a broken bracket. The centre is blocked up with a square block of wood for which a core-box can be readily made. The core-prints, FF, are formed by a round piece of wood. Round extensions to the core, to correspond with the prints, can be stuck on with clay-water.

Cores and prints for the bolt-holes can be inserted if required.

A broken pipe, Pl. **4**, Fig. 8, is given wooden prints and used as a pattern, the core being made in halves by a strickle. In small work of this nature there is little contraction, and a slight increase in size to allow for machining can be made by increased rapping of the pattern in the mould.

Pl. **4**, Fig. 13 shows how a pattern for a long pipe can be used for moulding a shorter one. The process is known as *stopping-off*. The pattern is moulded first; then a new flange is moulded by the stopping piece B, the portion D of the mould being filled in with sand.

Burning-on is the practice of casting new metal on a damaged casting.

It is used where it is more convenient and economical than making a new pattern and mould.

In the case of the pipe flange, Pl. **4**, Fig. 14, the new mould is made in loam against the casting. A pouring-runner and a flow-off channel are provided. The casting is first heated in a core-oven; the new mould is made up quickly, red-hot weights being placed as near as possible to the broken part to preserve its heat. A large quantity of molten metal is

poured into the runner and allowed to flow through the mould and then to waste. The portion of the original casting inside the mould is gradually heated up to fusing point, and, when this occurs, the pouring is stopped.

This process requires great skill on the part of the moulder. It is likely to be more successful with the copper alloys than with those of iron.

10. *Iron founding*

1. **The cupola.** Pl. **5**, Fig. 2 (*see also* Pl. **6**, Fig. 2), shows a simple design of cupola installed in the Workshops S.M.E., which is suitable for melting 25–30 cwt. of iron an hour. It is constructed of $\frac{3}{8}$-inch steel sheet, lined with $4\frac{1}{2}$-inch firebrick set in fireclay, and mounted on a steel pedestal, the legs of which are set in concrete.

The drop bottom is of $\frac{3}{8}$-inch steel sheet. The tuyères, slag hole, tapping hole, running spout (let through the foundry wall) and coloured sight glasses are all indicated in the figure.

2. **Blowers.**—The air-blast for a cupola is provided by a blower, which may be either of the Roots' or centrifugal type. *See* Sec. **16** for particulars of blowers. The Roots' blower has the advantage of a more positive action, and in the past has been largely used, but the modern tendency is to use centrifugal blowers, which have a higher efficiency, are cheaper and easier to maintain and are much quieter in operation.

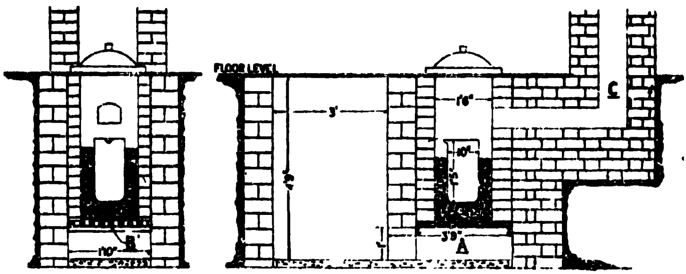
3. **Relining a cupola.**—The firebricks should be laid in the best quality of fireclay which should be thoroughly mixed with water, and thin enough to ensure close joints. Each layer of bricks should be bedded upon the clay grouting as quickly as possible, and as each brick is laid it should be lightly tapped down with a hammer to ensure a solid bearing. Instead of using a trowel to spread the thin clay, the bottom and one side or end of each brick may be dipped into the clay before being laid. The joints between bricks should never be more than $\frac{1}{4}$ inch thick.

A clearance of $\frac{1}{2}$ to $\frac{3}{4}$ inch should be left between the bricks and the shell of the cupola. This space is filled with grouting made of about equal parts of fireclay and old firebricks ground or broken up small.

4. **Drying the lining.**—After a cupola has been lined it should be dried as slowly and completely as possible, otherwise the lining will be burnt much more by the first blow than need be the case.

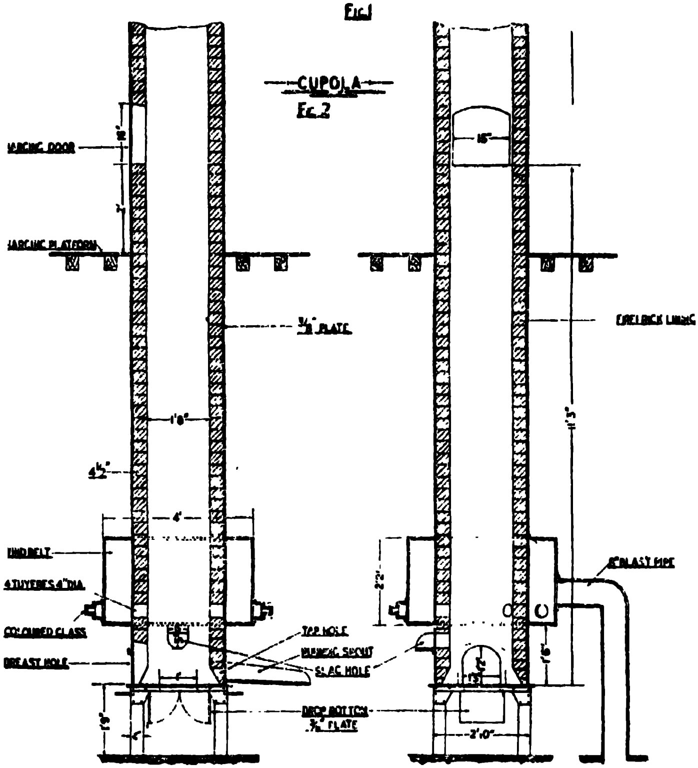
To carry out the drying, the drop doors are closed and covered with sand to a depth of 2 to 3 inches to prevent the heat from warping them. Wood is placed on the sand in an

PLATE 5.



—CRUCIBLE FURNACE—
Fig. 1

—CUPOLA—
Fig. 2



open manner so as to allow it to catch fire easily and then a charge of coke or coal, 12 to 18 inches, is added. When the fire is well under way more fuel should be added to form a bed of ignited fuel about 2 feet deep. Finally, all draught passages should be closed and the fire left to burn out before dropping the bottom to get the cupola ready for a blow.

5. **Preparing a cupola for first blow.**—After the drying out, the surface of the lining should be given a thin coating of *purimachus* cement or grouting made with ganister or fireclay. A handful of salt should be put in the pail of water used to wet the ganister or clay. This treatment will put a glaze on the face of the lining, which is very effective in resisting the cutting-out or burning effect of the first blow, which is always harder on the lining than subsequent blows. The shorter the first blow can be made the better, and care should be taken to keep the blast as mild as possible.

6. **Charging a cupola.**—The drop bottom must first be fixed in position and covered with 4 inches of sand which is well rammed at the corners. The charge consists of pig iron and scrap, foundry coke or coal and limestone. The purpose of the limestone is to float upon the surface of the molten metal, dissolve the impurities and form a slag which is periodically tapped off.

A small coke fire is started on the sand bottom and a bed charge of about 3 cwt. of coke is made up. The coke is allowed to burn for about 1 hour to warm everything up and then the breast hole is made up with ordinary moulder's sand or clay, kept in position by a steel plate. A metal charge of about 4 cwt. of mixed pig and scrap iron is then placed on top of the bed charge together with 7 lb. of limestone. This is followed by a charge of about 56 lb. of coke, then by another charge of 4 cwt. of metal and so on until sufficient charge has been fed in.

The tapping hole is then closed with a clay stopping plug or " bot " and the main blast turned on.

In time, the iron will begin to melt, drops falling down through the coke to the bottom.

The cupola is fed at the top with fresh coke and iron as required. The operator can watch the amount of molten iron in the bottom through the sight glass D.

When it is required to run out metal, the bot is spiked and the metal run into a ladle (Pl. 4, Fig. 9) which has been lined with yellow loam 1 inch thick. When the ladle is full, a new plug of clay is inserted in the tapping hole.

As metal is run off, coke, iron and limestone are fed into the top, and this process is continued as long as there are moulds to fill.

At the end of a blow, the bottom is dropped and any remaining slag, &c., falls out.

The slag must not be allowed to set in the cupola or it will probably have to be relined.

7. **Cleaning a cupola after a blow.**—The slag sticking to the lining must be chipped off, care being taken not to remove the glaze (or cinder) coating of the lining. The glaze that a blow or two will produce on the surface of the lining will protect it better than daubing. The cupola having been picked out to the proper form, the next operation is to fill up all the holes and daub the surface of the melting zone with ganister. The smaller the amount of daubing the better. It should rarely be allowed to exceed ½ inch in thickness at any part. The tuyèrés should then be cleaned and the slag hole and tapping holes repaired with ganister. When the melting zone becomes burnt out so badly as to enlarge it 4 inches or more beyond the general lining, thus permitting the blast to escape between the charge and the lining, it should be repaired with split bricks 2 inches thick. These should be bedded with good clay against the solid lining, thus reducing the diameter of the melting zone to its original value.

8. **The mixing of metal.**—For service purposes grey pig iron will normally be used. This can be obtained in four grades, viz. :—

No. 1 pig, which shows a highly crystalline fracture, the crystals being large and evenly distributed. It is very dark grey in colour, due to the large, lustrous flakes of graphite, which are easily distinguishable on the fractured surface with the naked eye.

The iron when melted is very fluid, and makes fine sharp castings for ornamental work where strength is not required. It is deficient in strength and hardness.

No. 2 pig has qualities which are a medium between Nos. 1 and 3.

No. 3 pig, which contains less free graphite than Nos. 1 or 2, and appears lighter in colour at a fracture, since the flakes are smaller. The crystals are smaller, and the fracture is more regular.

The metal is slightly less fluid when hot than No. 1 pig, but it is harder and stronger. It is fairly easily machined. It should be mixed with scrap iron for general work.

No. 4 pig is harder and stronger than the others, and can only be used by itself for rough castings which do not require machining ; mixed with soft scrap it hardens the resulting metal.

To summarize, grey iron is easy to melt and has comparatively little contraction, is soft and easily machined but has a low tensile strength. White iron has opposite properties.

These simple rules refer to scrap as well as pig, although, other things being equal, scrap is harder than pig.

A good mixture for general work is :—

No. 3 pig	50 per cent.
Selected scrap	50 per cent.

For best machine castings use :—

No. 3 pig	75 per cent.
Selected scrap	25 per cent.

The best scrap is that from old engines and machinery; the worst is that from old pipes, which should be avoided.

When breaking up scrap, the type of fracture is noted, and different piles are made of varying greyness and hardness. A decision is then made as to what proportion of each grade of scrap should be added to the pig iron to obtain the necessary degree of hardness, &c. for the work in hand, bearing in mind that the cupola has a slight hardening effect.

Metal can be fairly well mixed in this way by an experienced foundryman, and application of the foregoing principles will enable an experienced man to modify the nature of the castings he produces. Whenever possible, however, laboratory control should be secured.

When making up a charge, an allowance of 20 per cent. loss must be made. If a solid pattern of soft wood is used, a rough method of arriving at the weight of the casting can be obtained by weighing the pattern and multiplying by 16.

9. In **pouring** molten iron, the main principles are :—

i. Allow as little slag as possible to enter the pouring-runner, by skimming the molten iron with a rectangular bar of iron as it is being poured.

ii. Do not pour too hot, or contraction will be aggravated; do not pour too cold, or the metal will not properly fill the mould.

(The correct temperature for small castings will be indicated by the formation of a lined film of oxide on top of the metal in the ladle.)

iii. Pour steadily, and always keep the feeding-cup full. If this is done, slag and dirt will float on the top; otherwise it will go into the mould.

Gas will be given off from the top and vents of the mould; this should be lit, otherwise the foundry would be filled with CO, which is a poisonous gas.

Castings should be left to cool in the sand, as this has an annealing action which removes internal strains due to contraction.

10. **Fettling** consists of the removal of fins, runners, risers, and sand from the casting, and generally cleaning it up. The runners are sometimes hit off with a hammer, but when this is done care should be taken to see that the adjoining portions of the casting are not damaged. In the case of brass castings and thin iron castings the runners must be sawn off. The burnt sand may be removed by a wire brush or scaling tool, but a sand blast is preferable. The irregularities are chipped off or ground off on the emery wheel.

In the manufacture of repeat articles a tumbler is employed in which many castings are rotated at one time; it will remove sand cores and smooth off irregular corners.

Castings are finally treated with a wire brush, and should be delivered to the machine shop free from sand. When sand is embedded slightly in the surface, machining is extremely difficult.

11. *Brass moulding and founding*

1. **General.**—This section describes the production of castings in any of the usual copper-tin or copper-zinc alloys, and in aluminium.

The methods of using green sand, dry sand, and loam are practically the same as in iron moulding; the green-sand method is the one usually adopted.

Any yellow loamy sand, not too close in texture, is suitable, but no coal dust should be added. About one-eighth of flour is sometimes mixed with the sand when a fine surface is required.

For brass and copper alloys, the moulds are faced with flour or French chalk; for aluminium, with French chalk or plumbago.

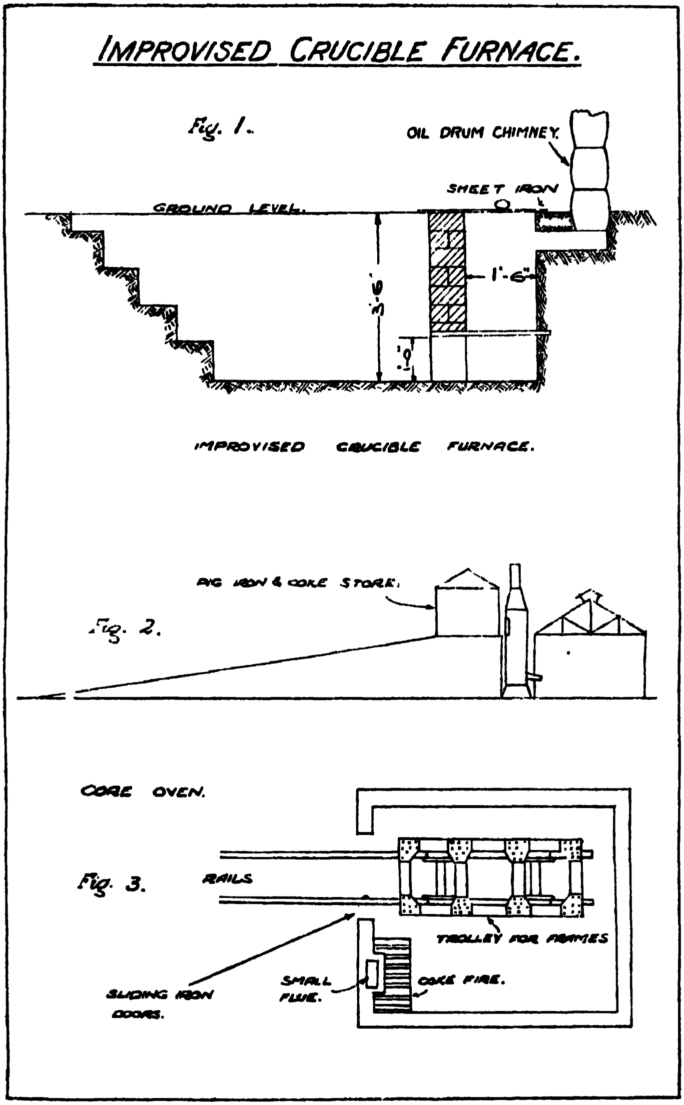
Moulds for copper alloys require a high pouring-runner to give ample pressure in the mould. Aluminium is so fluid that it can be poured with very little head.

The metals are placed in a crucible and heated in a coke fire. When the metal is molten it is usually poured direct from the crucible, the limiting content of which is 100 lb.

The correct temperature for pouring is indicated by the formation of a wavy skin in the case of copper alloys, by a purple skin in the case of aluminium, and by the smouldering (not burning) of paper thrown on the surface in the case of white metal.

The fumes of molten brass are poisonous, and good ventilation is therefore essential. If brass casting is a frequent operation, a minimum of 2500 cu. feet of air space per person

PLATE 6.


IMPROVISED CRUCIBLE FURNACE.
Fig. 1.
OIL DRUM CHIMNEY.
SHEET IRON
GROUND LEVEL.
3'-6"
1'-6"
9"
IMPROVISED CRUCIBLE FURNACE.
PIG IRON & COKE STORE.
Fig. 2.
CORE OVEN.
Fig. 3.
RAILS
TROLLEY FOR FRAMES
SLIDING IRON DOORS.
SMALL FLUE.
COKE FIRE.

employed should be allowed, and a good ventilating system should be provided. This is governed by regulations under the Factory and Workshop Act, published in the form of a notice, which should be posted in the shop.

2. **Crucible furnaces.**—Pl. 5, Fig. 1 shows a crucible furnace, and is self-explanatory. The bricks, preferably fire-bricks, are lined with fire-clay. A is the ashpit, B the firebars, C a natural-draught flue.

It is to be noted that E. & M. companies carry certain foundry plant, including crucibles, small moulding boxes and an electric blower. The necessary furnace must be improvised by excavation in the ground or otherwise.

For field service use a satisfactory type can be made by digging an inclined or stepped excavation, and building therein a brick wall and firebars, Pl. 6, Fig. 1; old 5-gallon oil drums can be utilized to make a chimney about 12 feet high.

To charge the crucible, 1 foot of coke is laid on the firebars and lit. The crucible, made of fireclay and plumbago, is placed on this and packed round with coke, and the metal is placed in it. The damper is opened and the metal should be melted within an hour.

Additional metal can then be added to the molten metal in the crucible to make up the charge.

Crucibles for brass work are very brittle, especially when damp. New crucibles should be heated up very gradually, near (not in) a furnace for 24 hours before use, to avoid cracking; old ones, when quite cold, should not be put into a hot fire.

A crucible is withdrawn from the furnace with crucible tongs, and the metal is poured in the usual way, great care being taken to skim away the slag.

As stated before, crucible furnaces are also suitable for iron melting when the quantities involved are under 100 lb.

Portable oil-fired crucible furnaces can be obtained. Crucible furnaces are, however, so easy to build or improvise that the heavy and expensive *portable type* will not be of much use to the military engineer.

12. *Miscellaneous*

1. **Steel castings.**—The difficulties experienced in the production of steel castings are chiefly (*a*) the large amount of contraction, owing to the high temperature of molten steel, (*b*) the frequency of blow-holes.

Moulds for steel are made mainly in dry sand, faced with silica paint or tar. High pouring-runners are used, special arrangements for skimming slag are adopted, and the molten metal is poured from the bottom of a ladle with straining

baffles. Owing to the specialized nature of the process, steel castings cannot usually be made in an army workshop.

2. **Malleable castings** are made of cast iron, from which the carbon is drawn away from the surface by a process which may be described as the opposite of case hardening. This is effected by packing the castings with red hematite ore in a closed metal-container which is maintained at a red heat for several days.

Malleable castings are used for articles of rather complicated shape, which would be expensive to forge by hand, and which have to resist shock. The modern tendency is to substitute steel castings or drop forgings.

13. *Foundry layout*

1. The fixed equipment of a military foundry will consist of :—

i. A cupola.
ii. A brass furnace.
iii. A drying-oven for moulds and cores.
iv. A core-maker's bench.
v. A sand-mixer.
vi. A travelling overhead crane.
vii. A fettler's bench.
viii. A dry emery wheel.

The floor will be of sand about 2 feet deep; water and compressed air should be laid on.

The cupola should be outside the building, but capable of being tapped from the inside.

The drying-oven doors should be flush with one of the walls, and the drying-oven built out as an annexe. A core-oven for small cores may be provided as well.

Special attention should be given to labour-saving arrangements for handling pig iron, scrap, and coke, which should be stored near the cupola and, if possible, at such a height as to avoid vertical lift for charging.

The building itself should be fireproof, relatively high, well ventilated, and well lighted.

For Bibliography, see page 686.

CHAPTER IV

BLACKSMITHS' WORK

14. *Introduction*

1. **Blacksmiths' work** consists mainly in the working of bars, &c. of wrought iron and mild steel into the required shape, whilst hot, by means of hammer blows.

2. **The smiths' hearth** in its portable form has the air-blast provided either by hand-actuated bellows (as in the *Forge, double bellows*) or by a geared-up centrifugal blower (as in the *Forge, field, G.S.*). Generally speaking, work up to the limit of size for hand-smithing can be heated in portable forges.

For convenience, however, and where output rather than portability is aimed at, it is desirable to provide fixed forges, constructed of metal or brickwork, in shops designed for permanent or semi-permanent use.

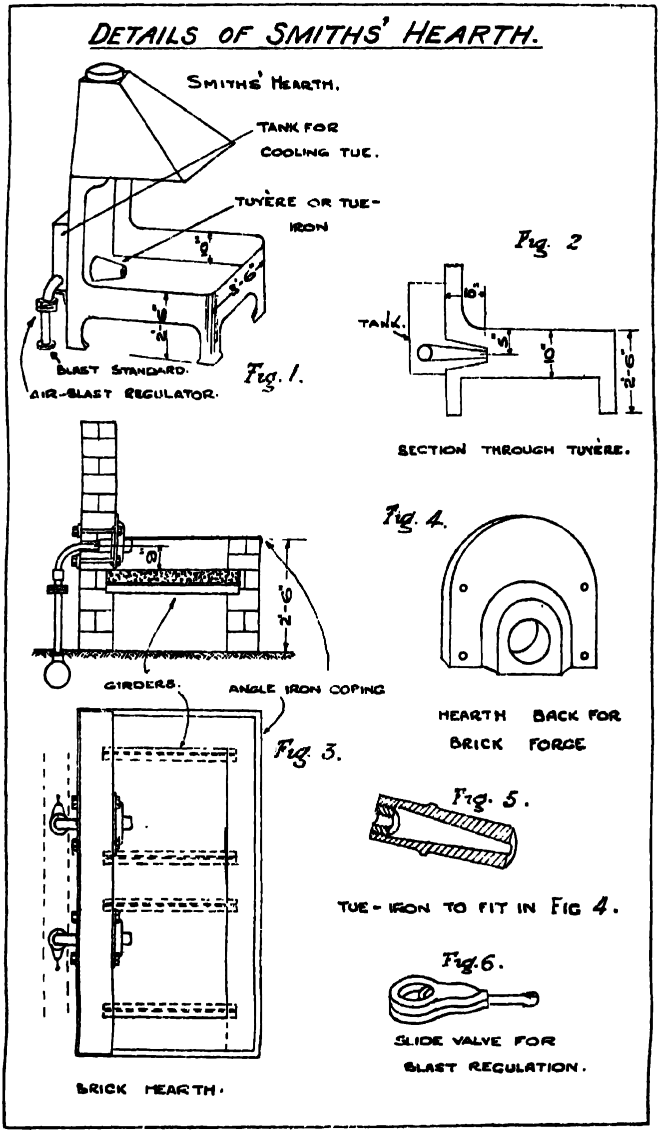
Pl. 7, Fig. 1 shows a common type of full-sized metal hearth, which can be obtained from manufacturers, or built up in a workshop. The top of the hearth is about 2 feet 6 inches above floor level, and the *floor* of the hearth is flat, and from 9 to 12 inches below the top edge. The air-blast, which is provided by a mechanically-actuated blower of some sort, is conveyed through the tue-iron which projects about 10 inches through the back of the hearth. The tue-iron, or tuyère, is conical in shape, often water-cooled, Pl. 7, Fig. 2, to prevent it from burning away, owing to contact with the flame, and is erected at such a level that the hole for exit of air is about 4 to 6 inches below the top edge of the hearth. The hearth is 3 feet 6 inches square.

The amount of air entering the tuyère, or tue-iron, can be regulated by a butterfly or slide valve, Pl. 7, Fig. 6, in the pipe connecting the shop air-main and the tue-iron.

3. **Accessories** of the hearth are :—

i. A water tank, conveniently placed near the forge, for quenching.
ii. A coal box.
iii. A water tank, or *bosh*, at the back for cooling the tue-iron (if it is water-cooled).
iv. A poker.
v. A coal *slice*.

PLATE 7.


DETAILS OF SMITHS' HEARTH.
SMITHS' HEARTH.
TANK FOR COOLING TUE.
TUYÈRE OR TUE-IRON
BLAST STANDARD.
AIR-BLAST REGULATOR.
Fig. 1.
Fig. 2
TANK.
SECTION THROUGH TUYÈRE.
Fig. 4.
HEARTH BACK FOR BRICK FORGE
GIRDERS.
ANGLE IRON COPING
Fig. 3.
BRICK HEARTH.
Fig. 5.
TUE-IRON TO FIT IN FIG 4.
Fig. 6.
SLIDE VALVE FOR BLAST REGULATION.

A sheet-iron cowl is placed above the top of the hearth, and should be fitted with a sheet-iron chimney of sufficient length to clear the smoke properly, or connected by piping to an exhaust fan.

Pl. **7**, Fig. 3 shows a type of brick hearth, which is easily built and gives satisfactory results. Such hearths are usually built in pairs, for economy of flue arrangements. A hollow space should be left underneath for the storage of ashes, &c. The cast-iron hearth-back, Pl. **7**, Fig. 4, is fixed to the brickwork by means of bolts. The tue-iron, shown on Pl. **7**, Fig. 5 (not water-cooled in this case), is inserted in the hearth-back. An angle-iron coping, shown on Pl. **7**, Fig. 3, runs round the outer top edge of the brickwork forming the hearth.

Both the above mentioned hearths are of the *back-blast* type; bottom-blast types, in which the tue-iron is underneath the fire, are equally common.

4. The **fuel** used is small coal, coke, charcoal, or breeze. If coal is used it should be bituminous and free from sulphur, &c., which is very detrimental to the working of iron.

5. The hearths described in this section, Pl. **7**, Figs. 1 and 3, are only types. The design might be modified by giving Fig. 1 a brickwork back, or Fig. 3 a cowl and chimney instead of a flue.

15. *Smiths' tools*

1. Smiths' tools have different names in different parts of the country. Those used here are the service names.

The anvil, Pl. **8**, Fig. 1, is made of wrought iron or steel, with a double-shear steel top welded on and hardened. It is placed on a metal or timber anvil block, of such a height that the top of the anvil is about 2 feet above floor level.

A 1¼-cwt. anvil is not suitable for taking big work where heavy blows are required. An anvil weighing 2½ cwt. is the smallest size suitable for permanent shop work. The anvil top must be perfectly true (it works hollow in course of time) and the edges must be square.

A is the horn or beak, B the core, and C the tail. The square, D, upon which work is cut is not hardened, to avoid damaging the cutting tools. The square hole, E, takes the shanks of *bottom tools*. Another square hole, near the beak, and a round hole at F are useful, but must be specified when ordering; they are useful for punching over. The quality of an anvil can generally be judged by its ring. A good anvil when struck with a hammer will give a clear, sharp sound, and a defective one a dull sound.

2. **Hammers.**—The hammer in most common use is the hand hammer (*hammer, fitters', 32-oz.*), which has a broad,

slightly-rounded face at one end, for general work, and a small rounded end, or *ball pane*, for small work, such as countersunk riveting, at the other end (Pl. **8**, Fig. 2).

The *hammer, smiths', sledge*, 10-*lb.*, and the *hammer, smiths', uphand*, 7-*lb.*, Pl. **8**, Fig. 3, are for striking heavy blows. In this connection, it must be pointed out that a smith working single-handed can cope only with very small work which can be hammered into shape by means of a hand hammer. For heavy work he requires a man to strike for him with a 7- or 10-lb. hammer, whilst the smith turns the work, and indicates the spot where the blow should come by tapping it with his hand hammer.

3. **Blacksmiths' tongs.** Tongs may be divided broadly into three classes, according to the shape of the *nose* or *bit* which holds the work :—

i. Flat or square ; Pl. **8**, Figs. 5 and 6.
ii. Round hollow bit ; Pl. **8**, Fig. 7 (*a*).
iii. Angle or V (or square) hollow bit ; Pl. **8**, Fig. 7 (*b*).

All tongs should be properly fitted to the work they have to hold, and should come in contact with it throughout the whole length of the jaw (Pl. **8**, Fig. 6 (*a*) shows correct and (*b*) and (*c*) incorrect methods).

It will be found advantageous if the bits of flat tongs have a longitudinal central groove, as this gives a better grip of the work. To relieve the hand of the smith from the constant pressure which would otherwise have to be exerted on the tongs when holding the work, a ring is fitted over the handles, and is driven up until tight. The anvil, or pick-up, tongs, Pl. **8**, Fig. 8, are not intended for gripping work when forging, but for picking up hot articles, tempering, &c.

The measuring tools used are the *rule, smiths', brass*, 2-*fold*, 2-*foot*, the *gap gauge* (N.I.V.), Pl. **8**, Fig. 10, and the *double callipers* (N.I.V.), Pl. **8**, Fig. 11.

4. The **cold set,** Pl. **8**, Fig. 12 (*b*), and the **anvil cutter,** or **hardie,** Fig. 12 (*a*), are each used to cut cold bars.

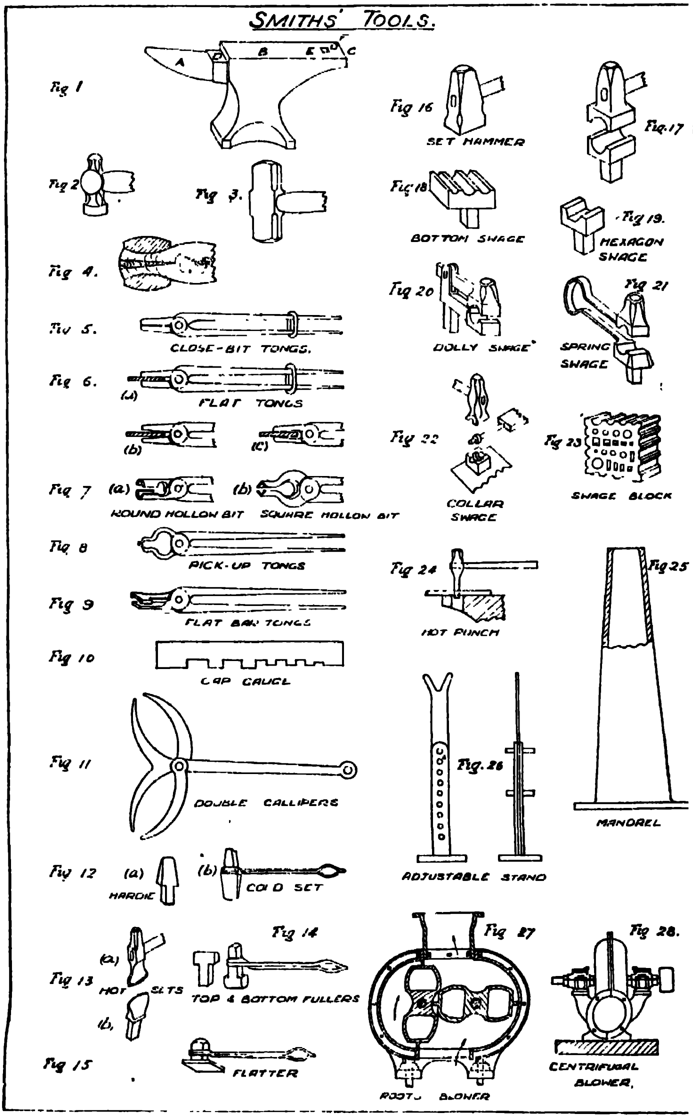
The anvil cutter has a square shank which fits into the hole in the anvil.

The cold set is made of hardened and tempered steel. Its cutting-edge is ground to 60°, and should be slightly convex to prevent the corners from chipping off. It is better without an eye for a handle. The handle consists of a thin iron bar fixed as shown.

Care should be taken to see that the cold sets and anvil cutters are not used on hot material, or the temper will be drawn.

5. The **hot set,** Pl. **8**, Fig. 13, is used for hot working. It is driven in deeply, several blows being given at the same

PLATE 8.


SMITHS' TOOLS.
Fig 1
Fig 2
Fig 3.
Fig 4.
Fig 5.
CLOSE-BIT TONGS.
Fig 6.
FLAT TONGS
(a)
(b)
(c)
Fig 7 (a) (b)
ROUND HOLLOW BIT
SQUARE HOLLOW BIT
Fig 8
PICK-UP TONGS
Fig 9
FLAT BAR TONGS
Fig 10
GAP GAUGE
Fig 11
DOUBLE CALLIPERS
Fig 12 (a) (b)
HARDIE
COLD SET
Fig 13 (a) (b)
HOT SETS
Fig 14
TOP & BOTTOM FULLERS
Fig 15
FLATTER
Fig 16
SET HAMMER
Fig. 17
Fig 18
BOTTOM SWAGE
Fig 19.
HEXAGON SWAGE
Fig 20
DOLLY SWAGE
Fig 21
SPRING SWAGE
Fig 22
COLLAR SWAGE
Fig 23
SWAGE BLOCK
Fig 24
HOT PUNCH
Fig 25
MANDREL
Fig. 26
ADJUSTABLE STAND
Fig 27
ROOTS BLOWER
Fig 28.
CENTRIFUGAL BLOWER.

spot; by the time the bar has been turned completely round, the set has almost severed it. In use the set becomes hot; therefore, after every four or five blows it is cooled in water.

A hot set is made of tool steel, not hardened as it would soon lose its temper, and its edges are ground to 30° and of slightly convex form. It is preferably made with an eye for a wooden handle.

6. **Fullers,** Pl. **8,** Fig. 14, are very blunt chisels with well-rounded edges; their size is denoted by the size of the groove they are capable of making. They are made both as top and bottom tools, and are used for indenting work in certain operations, hereafter described.

7. The **flatter,** Pl. **8,** Fig. 15, is used for flattening and finishing plane surfaces, and for removing hammer marks.

8. The **set hammer,** Pl. **8,** Fig. 16, is a similar but smaller tool, used for forming shoulders and getting into corners. Flatters and set hammers are sometimes required with square edges, but, whenever the work will permit, the corners should be well rounded to avoid any tendency to start a fracture in the work.

9. **Swages,** Pl. **8,** Figs. 17 to 21, are made as both top and bottom tools for finishing work of circular, square, hexagonal, or other forms. The top and bottom tools are sometimes united, as in the dolly, Fig. 20, or the spring swage, Fig. 21; with the latter the smith is able to work single-handed.

10. The **swage block,** Pl. **8,** Fig. 23, is usually made of cast iron and should be installed in every smithy; it embodies a wide range of shapes and sizes, and avoids the use of the large number of bottom swages that would otherwise be required.

11. A **collar swage** is shown on Pl. **8,** Fig. 22.

12. **Punches** are made either round or square. The work to be punched is raised to a bright red or white heat and placed on the anvil, and the punch is driven half-way through; it is then reversed, and a dark spot in the iron shows the position of the hole, which enables the smith to set the punch to pierce the metal so that the hole is accurately punched through. During the second operation, the work is laid either on a bolster, Pl. **8,** Fig. 24, or placed over the hole in the anvil (or swage block), and the punch then passes freely through.

13. **Drifts** are used to finish holes that have been punched smaller than the required dimensions. They may be taper or parallel, and of any desired section. Drifts are smooth, and being driven through the punched holes, enlarge, shape,

and smooth them while the metal is red hot. Smooth drifts are rarely absolutely parallel, or their withdrawal would be a matter of great difficulty; the sides are usually tapered about 4°.

14. The **smiths' mandrel,** Pl. **8,** Fig. 25, is a conical casting employed chiefly in making rings. Small taper mandrels, or *beak irons,* which fit in the square anvil hole, are also used.

15. An **adjustable support,** Pl. **8,** Fig. 26, for long work, a *vice, standing,* 80-*lb.*, and a tool stand will, together with the above tools and a mechanically-driven blast-producer, complete the initial equipment of most smithies.

16. Appendix V gives the tools, &c. to be ordered when a shop is being equipped. The N.I.V. hand tools can usually be made by the smith.

16. *The air-blast*

1. A small smith's fire requires about 45 cubic feet of air a minute, and a large one about 90 cubic feet, both against a pressure of 1½ oz. to 6 oz. (2·5 inches to 10 inches of water). Small fires with the blower close to them work well with 1½ oz.; large fires will require 3 oz. Allowing for pipe friction, &c., 100 cubic feet per minute should be taken as the basis for the normal fire having a 1¼-inch tuyère pipe.

The blast can be produced either by a Roots' blower, Pl. **8,** Fig. 27, or by a centrifugal blower, Pl. **8,** Fig. 28.

The Roots' blower has the advantage of a positive action; it is, however, noisy and subject to wear.

The centrifugal blower is silent running, its wear is negligible, and it is lighter for a given output than the Roots' blower. Owing to its non-positive action, if undue friction is caused in the air main through bends, obstructions, &c., the necessary volume of air will not be obtained.

On the other hand, the centrifugal blower automatically maintains a fairly constant pressure at varying outputs, so that if several fires in a group supplied by a common blower are out of action, the blast is not increased at the remaining fires as would be the case with a Roots' blower. Centrifugal blowers are more commonly used than Roots' blowers in modern installations.

The method of drive, relative speed, &c. will often decide which is the best type to instal.

Details of each type are given in Tables **B** and **C** on p. 50, from which comparisons can be made.

These tables must be taken as approximate only, since makers will vary the details slightly. It is a good practice

Table B.—Particulars of Roots' blowers

									Remarks
Volume of air in cubic feet per minute	95	130	225	355	460	600	800	1,300	In actual practice, all fires in a smithy will rarely be going *full blast* at one time, so these figures can be modified. It is assumed that a 1¼-in. tuyère pipe is used.
Maximum number of revolutions per minute	300	300	300	300	300	300	300	400	
Number of fires, 1¼-in. tuyère (full speed)	1	1	2	3	4	6	8	13	
Metal melted per hour at full speed—tons	—	—	—	½	¾	1	1½	2	
Diameter of outlet	2 in.	2½ in.	3 in.	4 in.	4½ in.	5 in.	6 in.	7 in.	
B.H.P. for ½-lb. pressure (smiths' forges)	0·25	0·35	0·61	1	1¼	1½	2¼	3½	
B.H.P. for ¾-lb. pressure (cupola work)	—	—	—	—	2	2¼	3	5	
Floor space occupied (approximately)	—	—	—	29 in. × 36 in.	36 in. × 36 in.	36 in. × 36 in.	46 in. × 36 in.	49 in. × 36 in.	

Table C.—Particulars of typical centrifugal blowers

								Remarks
Volume of air in cubic feet per minute	100	200	400	600	800	1,600	1,600	The amount of air delivered will be approximately proportional to the speed.
Revolutions for 6 in. of water pressure	4,800	4,500	4,250	3,850	3,500	2,700	2,500	
Number of fires, 1¼-in. tuyère	1	2	4	6	8	12	16	
Metal melted per hour (cupola work)	About half the quantities given for Roots' per 100 cubic feet.							
Diameter of outlet	3 in.	4 in.	5 in.	6 in.	8 in.	9 in.	10 in.	
B.H.P. for ¼-lb. pressure (smith's work)	¼	½	1	1½	2½	4	5	
Diameter of blower	10 in.	13 in.	17 in.	20 in.	25 in.	30 in.	34 in.	
Diameter of impeller	6 in.	8 in.	10 in.	12½ in.	15 in.	17½ in.	20 in.	

to allow 25 per cent. more power, owing to belt friction, wear, shafting, &c. Where it is desired to blow a cupola with the same blower that delivers air to the smithy, a Roots' blower should be specified.

2. **The main blast pipe** should be taken in a trench or in the open at the back of the hearths; it should be of the same diameter as the outlet of the blower. The connection to each forge is usually by 1¼-inch pipe, tapped straight into the blast main; in the connecting pipe, the regulating slide, Pl. 7, Fig. 6, is placed.

When a Roots' blower is installed, it is good practice to put a *dead-weight relief valve* in the blast main, to prevent an excessive air pressure at any one forge when the others are shut off. Excessive air-blast tends to burn away the surface of the metal being worked, and to form scale.

The arrangement of the smithy is dealt with later, but it should be noted here that bends in the blast main should, as far as possible, be avoided, especially where a centrifugal fan blower is employed. The blast main should invariably be carried from 4 to 6 feet past the last fire.

17. *Smiths' work.*

1. Work performed by a smith not provided with a power hammer will consist of a combination of some of the following operations:

i. Upsetting or jumping-up.
ii. Drawing-down.
iii. Cutting-out.
iv. Bending.
v. Punching and drifting.
vi. Welding.

If a power hammer is provided, *add*

vii. Stamping.

2. **Upsetting** is the operation of swelling or increasing the thickness of a bar in one place, its length being at the same time reduced. It is only used when the increased thickness required is not great in proportion to the original dimensions.

If it is the end of a bar that is required to be upset, the end is heated to a bright red heat and hammered, or the smith holds the bar vertically and strikes the heated end on an anvil. Pl. 9, Fig. 1 (*a*), (*b*), and (*c*). If the work is bulky and short, it is held vertically on the anvil by the smith, while the striker hammers the upper end, Fig. 1 (*b*). Only a small portion of the work can be done at each heat, and the operation is repeated until the required shape is produced.

3. **Drawing-down** is the process of increasing the length of any piece of iron, and at the same time reducing its cross-section.

The simplest example is the formation of a point to a square bar. The bar is heated to a bright red, and the metal is beaten down at the edges, the work being turned frequently and struck an approximately equal number of times on each face, to prevent the metal spreading out sideways, as the length increases and the thickness decreases.

If the bar B, Pl. 9, Fig. 2, is to be drawn-down to shape A, it is placed between top and bottom fullers and indented where the change of section is required (Pl. 9, Fig. 5). The bar must not be laid on the edge of the anvil as shown in Pl. 9, Fig. 3, or the material will be damaged as it would be with a set.

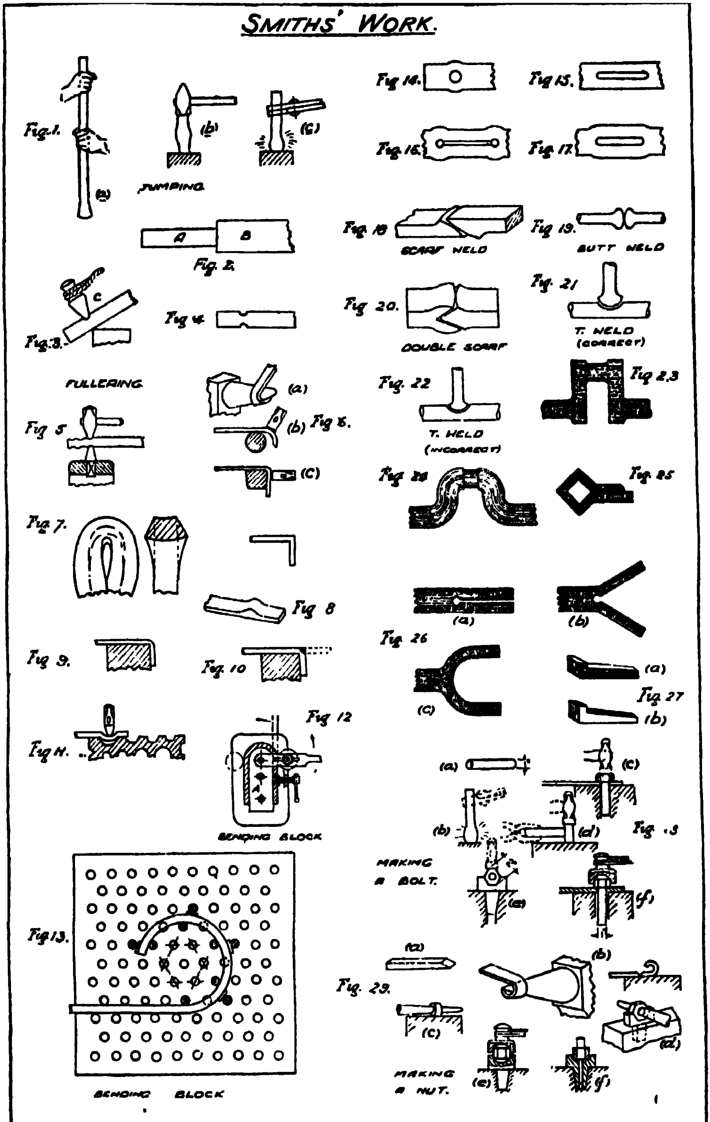
Sets are not used in such indenting, as they would divide the fibres of the metal; round-faced fullers simply alter the direction of the fibres without breaking their continuity. The preservation of the continuity of fibre is of primary importance in forged work; what may appear to be round-about methods will often be resorted to in order to preserve that continuity. *Fibrous iron may readily be damaged by nicking with a sharp tool.* A bar of iron, nicked round and broken off suddenly, shows fractured surfaces as highly crystalline as those of cast iron. When the work has been indented with the fuller, the metal along A is drawn-down or thinned by a succession of blows from a hand or sledge hammer. Fullering and hammering not only lengthens the bar, but also spreads it sideways. If the bar is to be equal-sided, the widening has to be prevented by rapidly hammering the sides alternately with the faces. After every few blows given on the faces, the smith turns the bar quarter round during the brief interval between two blows, and the iron receives several blows upon the edges as a corrective to those given on the faces. Drawing-down is always commenced from the end of a bar, as much as possible being done in one heat.

With long bars or special work, it may be found advantageous to use the fullers to a greater extent to help in the actual drawing-down. Pl. 9, Fig. 5 shows this and is self-explanatory.

The drawn-down bar will be rough and show hammer marks; finishing is done with the flatter. A round bar is drawn-down in a similar way, swages being used for finishing.

4. **The process of cutting-out** is performed by chisels (sets) and gouges; portions of the work are cut away completely in trimming to shape, or in some cases a split may be made and opened out, or the ends may be bent to the shape

PLATE 9.


SMITHS' WORK.
Fig. 1.
JUMPING
Fig. 2.
Fig. 3.
Fig. 4
FULLERING
Fig. 5
Fig. 6.
Fig. 7.
Fig. 8
Fig. 9.
Fig. 10
Fig. 11.
Fig. 12
BENDING BLOCK
Fig. 13.
BENDING BLOCK
Fig. 14.
Fig. 15.
Fig. 16.
Fig. 17.
Fig. 18
SCARF WELD
Fig. 19.
BUTT WELD
Fig. 20.
DOUBLE SCARF
Fig. 21
T. WELD (CORRECT)
Fig. 22
T. WELD (INCORRECT)
Fig. 23
Fig. 24
Fig. 25
Fig. 26
Fig. 27
MAKING A BOLT.
Fig. 29.
MAKING A NUT.

required. This method is very suitable for thin work, where welding would be difficult. With iron, a hole must first be punched to terminate the cut and to avoid the tendency to split along the direction of the fibres.

5. **Bending** can in certain cases be satisfactorily carried out cold, but it is preferably done at bending heat, *i.e.* dull red. Bends may be made over the anvil edge or on the beak, on the swage block, &c., Pl. **9**, Fig. 6 (*a*), (*b*), and (*c*). In all cases the metal on the outer side of the bend is subject to a drawing-down action, that on the inner side being upset, Pl. **9**, Fig. 7. Hence a right angle formed from a straight bar on the anvil edge will take the shape shown on Pl. **9**, Fig. 9. The square bend or angle must, therefore, be made with a forged corner to supply the additional material required on the outside, which is either worked up with light hammers, Pl. **9**, Fig. 10, or, before bending, the bar may be upset at the place where the bend is to be made, Pl. **9**, Fig. 8.

Rings and eyes are bent over the beak of the anvil if of small size, or round a mandrel.

Pl. **9**, Fig. 12 shows a bending block, in which work is bent to any desired contour, over a replaceable block, A, by means of a lever and roller.

Pl. **9**, Fig. 13 shows a bending block, consisting of a cast iron plate drilled to take stout pegs, and is self-explanatory. The decision as to whether material is to be bent hot or cold must depend largely on its size. For cold bending of bars, plates, &c., the machine shown on Pl. **11**, Fig. 1, may be used.

6. **Punching, drifting, and drilling.** The operation of punching has been partly described in Sec. **15**. If the hole is deep, the hot iron closes round the punch, which should be withdrawn after every 3 or 4 blows, and cooled in water. Withdrawal of the punch will be facilitated by sprinkling powdered coal where the hole is to be punched. Methods of producing punched holes vary according to requirements. When a hole is punched with the tool shown on Pl. **8**, Fig. 24, the metal removed is equal in area to the punch end, and the width of the bar is only very slightly increased, Pl. **9**, Fig. 14; the bar is, therefore, weakened. If a conical punch is used, and the hole drifted afterwards, no metal is removed, and the edges of the hole are swelled in such a way as not to weaken the rod. Similarly, in producing a long slot, if area reduction is immaterial, a succession of holes can be punched and the intervening metal removed with a set. When it is desired to retain the area, two punched holes are made at either end, a set being used to unite them. The slot is then heated again,

jumped-up, and trued-up with a drift (*see* Pl. 9, Figs. 15, 16, and 17).

7. **Welding** is one of the principal operations performed by the smith. Most metals, when heated to melting point, change almost at once from solid to liquid state. Wrought iron, however, passes through an intermediate state, in which it becomes pasty; if two pieces in this condition be placed together, they will adhere when hammered. It is most important that the metal should be heated to the proper temperature for welding, as hammering will not join two pieces which are insufficiently heated; if overheated, the iron will be burnt and rendered useless. The metal which remains pasty over the widest range of temperature is the most easily welded, and in this respect wrought iron has a great advantage over steel. Wrought iron is weldable from a white heat, that is to say just below that at which sparks are given off, to a point 100° F. below it. The welding heat for steel is at a point where red heat begins to change to white heat. After removal from the fire, operations must be quickly carried out, or the heat at which a sound weld could be made will have passed. The next essential to the production of a sound weld is that the surfaces in contact should be perfectly clean; for instance, coal containing sulphur on the hearth will be detrimental to a good weld. Iron oxidizes at a high temperature, becoming covered with a thin film of scale (oxide of iron). This must be removed, otherwise a defective weld would be the result. Wrought iron can be heated up to a high enough temperature to melt this oxide without burning the iron; with steel, especially tool steel, a temperature high enough to melt the oxide would burn the steel. This necessitates using a flux to dissolve the oxide at a lower temperature, forming a slag which is easily expelled under pressure of hammer blows. The danger of burning is increased when the air-blast is too strong and the fire is oxidizing. Silver sand is the flux for iron; borax, or a mixture of 4 parts of borax to 1 part of sal-ammoniac, for steel. In order that air, scale, and dirt may be excluded from the joint, it is necessary to make the surfaces to be welded slightly convex; contact is then first made at a point, and slag, &c., is squeezed out as the remainder of the surfaces are joined under pressure of the hammer blows. To remove any scale that may be formed, the smith should use a wire brush just before contact is made.

To sum up, the essentials for a good weld are :—

- i. A clear fire.
- ii. A proper welding heat.
- iii. Exclusion and removal of air, dirt, and scale.
- iv. Quick smart work.

There are several types of welded joint :—

i. Single-scarf weld, Pl. **9**, Fig. 18. In this the length of the scarf equals $1\frac{1}{2}$ times the bar thickness.
ii. Double-scarf weld, Pl. **9**, Fig. 20.
iii. Butt weld, Pl. **9**, Fig. 19.
iv. T weld for flat bar, Pl. **10**, Fig. 15.
v. T weld for round bar, Pl. **10**, Fig. 16.
vi. Jump weld, which is another form of T weld ; Pl. **9**, Fig. 21 shows the correct and Fig. 22 the incorrect way of making a jump weld.

After welding, the work is finished off by means of appropriate swages, &c.

8. **Strength of welded joints.**—A butt weld is not so strong as a lap or scarf weld ; on being tested, it usually breaks at the joint. A good scarf weld will often be as strong as the solid bar ; but for design purposes, it is better to assess the strength of a weld at 75 per cent. of that of the solid bar. This allows for different standards of workmanship.

9. **Conditions of work.**—The method employed by a smith for any particular job will depend on the tools available, the shape of iron in store, the purpose for which the article is required, and the provision of a striker or not. The fibrous nature of wrought iron should be constantly borne in mind. It is stronger in the direction of its fibres than across them in the ratio of 21 to 17 ; any nicking with sharp tools will cut through the fibres and cause a tendency to fracture at that point. The direction in which work is subjected to the greater stress should always coincide with the longitudinal direction of the fibres. Curved work should not be cut from the solid, if it is possible to bend it to shape. To illustrate this, Pl. **9**, Fig. 23 shows a crankshaft slotted from the solid, and Pl. **9**, Fig. 24 a bent one. The former tends to snap off at the shoulders, the latter does not.

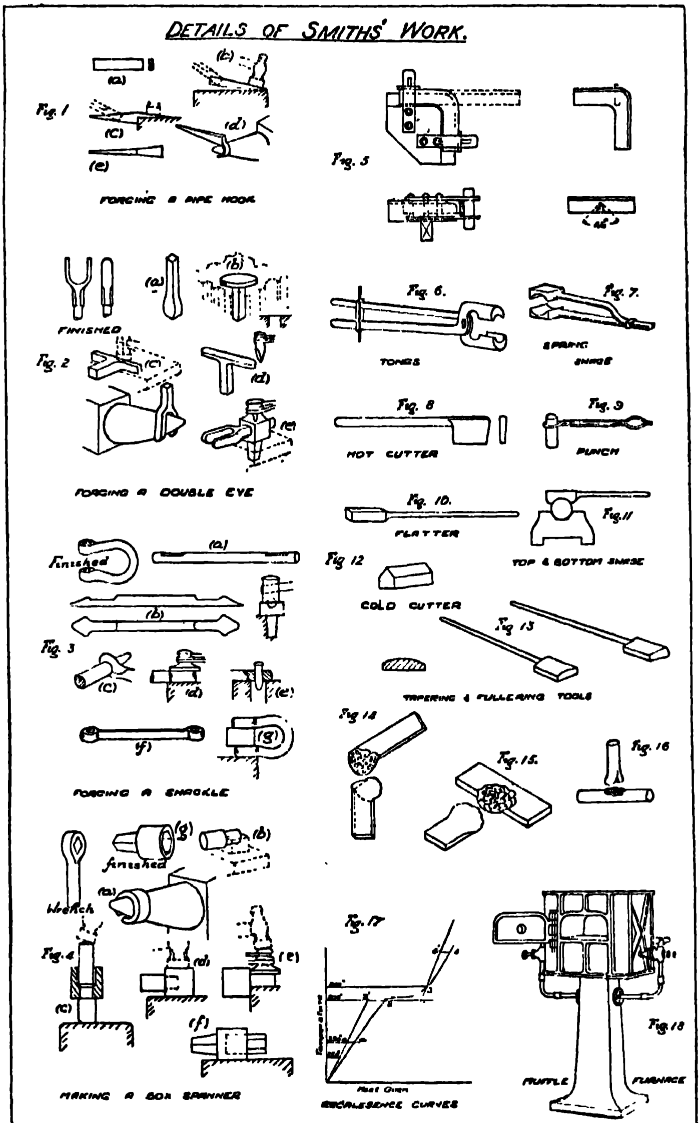
In forging the eye of a winch handle, Pl. **9**, Fig. 25, instead of making a solid end and drilling and filing a square hole, the bar is bent round a mandrel and welded, thus preserving the continuity of the fibre.

Pl. **9**, Fig. 26 shows the correct way of forming a fork from the solid bar.

Pl. **9**, Fig. 27 (*a*) and (*b*) shows the correct and incorrect way of forging a key which has to take side stresses.

10. **Smithing with iron and steel.**—Generally speaking, mild steel does not possess a visible grain except under the microscope, and its method of working differs from that for wrought iron. The average smith does better work with wrought iron, especially as regards welding. While wrought

PLATE 10.


DETAILS OF SMITHS' WORK.
Fig. 1
(a)
(b)
(c)
(d)
(e)
FORGING A PIPE HOOK
Fig. 5
FINISHED
Fig. 2
(a)
(b)
(c)
(d)
(e)
FORGING A DOUBLE EYE
Fig. 6.
TONGS
Fig. 7.
SPRING SWAGE
Fig. 8
HOT CUTTER
Fig. 9
PUNCH
Fig. 10.
FLATTER
Fig. 11
TOP & BOTTOM SWAGE
Finished
(a)
(b)
Fig. 3
(c)
(d)
(e)
(f)
(g)
FORGING A SHACKLE
Fig 12
COLD CUTTER
Fig 13
TAPERING & FULLERING TOOLS
Fig 14
Fig. 15.
Fig. 16
(g)
(b)
finished
(a)
Wrench
Fig. 4
(c)
(d)
(e)
(f)
MAKING A BOX SPANNER
Fig. 17
RECALESCENCE CURVES
Fig 18
MUFFLE FURNACE

iron can be worked almost up to fusing point, each different sample of steel seems to work best at a particular temperature, but never beyond a full red heat; otherwise it will become burnt and crumble to pieces under the hammer. Neither steel nor iron should ever be hammered at a so-called blue heat, *i.e.* after it has ceased to show red, or it will be much weakened. For these reasons, work has to be performed more quickly on steel than on wrought iron, and probably two heats will have to be given to it, whilst only one is necessary with iron. As a very rough guide, steel is better fitted for small, delicate, and intricate forgings, since there is not the same tendency to split along the fibres as with iron. For large work, iron is better, since it can be hammered through a greater temperature range.

11. **Examples of work.**—The following examples will serve to show how the smith executes some typical jobs :—

Forging a bolt in sizes up to ½ in.—Pl. **9**, Fig. 28 (*a*) to (*f*).

(*a*) Iron bar of correct dimensions.
(*b*) Jumping-up the end to form the bolt head. (Alternatively the head may be jumped-up in the vice using grip plates.)
(*c*) Head beaten down in *heading* tool.
(*d*) Head trued and new heat taken.
(*e*) Head shaped in hexagon swage.
(*f*) Edges rounded in cup tool.

In the case of medium sizes (½ inch to 1 inch) a quicker method is to weld the head on. In large sizes (over 1 inch) it is usually necessary to draw-out from the solid.

Forging a nut.—Pl. **9**, Fig. 29 (*a*) to (*f*).

(*a*) Material.
(*b*) Bend hot and nick.
(*c*) Weld round mandrel.
(*d*) Shape hexagon in swage.
(*e*) Round edges in cupping tool.
(*f*) Finally true the centre hole by drifting.

In the foregoing examples, the size of nut and bolt-head will of course be obtained from the standard tables.

Forging a pipe hook.—Pl. **10**, Fig. 1 (*a*) to (*e*). The figures are self-explanatory.

Forging a double-eye.—Pl. **10**, Fig. 2 (*a*) to (*e*).

Forging a shackle.—Pl. **10**, Fig 3 (*a*) to (*g*).

Forging a box spanner.—Pl. **10**, Fig. 4 (*a*) to (*g*).

Bending angle iron.—This is best done round a cast iron block, Pl. **10**, Fig. 5. The angle iron is heated where it is to be bent, and one end is clamped to the block, the other end being hammered round ; as it bends, it will be found that

the top flange will tend to pucker up on the inside; this is counteracted by a few blows with a sledge hammer. Irregularities on the outside are removed by a flatter. In making a square corner, a 45° piece is cut out, the bend is made, and the edges of the nick are scarfed and welded (*see* Fig. 5).

18. *The power hammer*

1. The power hammer is a very useful machine where heavy material has to be worked; it may be either steam or pneumatic. The latter can be electric-motor driven, and is made in various sizes complete with motors in self-contained sets. A handy size is the 3-cwt. hammer, *i.e.* a hammer in which the weight of moving parts is 3 cwts. A set of tools suitable for such a hammer is shown on Pl. **10**, Figs. 6 to 13. Work for the 3-cwt. hammer can be heated in an ordinary smith's hearth. Where a very large number of repeat articles is required, the power hammer can be used for *stampings* or *drop forgings*, which are made between dies of cast steel. Three pairs of dies go to a set. The white-hot metal is rough-shaped and then placed in roughing dies. Metal is squeezed out at the ends from between the faces of the dies. Next, stripping dies are used to remove the metal *fin*, and finally finishing dies. Heating between the processes will be necessary.

2. **Drop hammers.**—In works where drop forging is regularly carried out, it is usual to employ drop hammers for the work. In these, the hammer head, which may weigh several tons, is hoisted by ropes or belts and allowed to fall freely, whereas in the normal power hammer, the hammer head is carried on a piston rod and is forced down by steam or air pressure. In drop forging, there is normally only a small thickness of hot metal between the edge of the hardened dies, and if a piston type hammer is used, the jarring effect on the piston rod is much greater than in ordinary forging, where heavy blows are only struck when a considerable thickness of hot (and therefore soft) metal is interposed between the hammer and the anvil. In time this jarring may lead to fatigue fractures, and drop hammers are therefore used to avoid this danger.

3. **Simple die-sinking** is an expensive process, and should only be resorted to where a sufficient number of forgings is required to justify the initial expense. The sets of dies would normally be obtained from manufacturers; but, in emergencies, it is possible to make them in very solid chilled cast iron, with wrought iron bands shrunk round them. Another way is to make a *master* forging in hardened

PLATE 11.

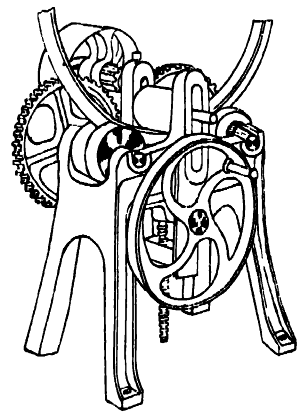
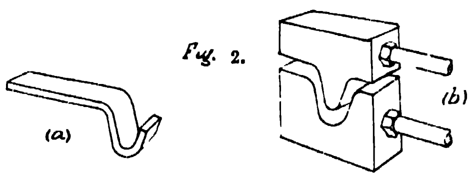


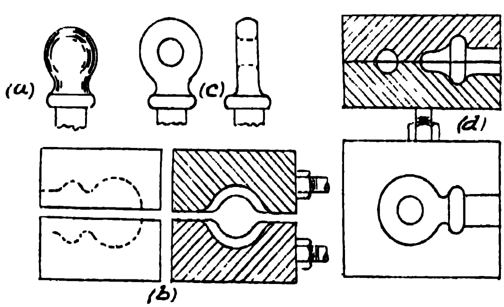
Fig. 1.

BENDING MACHINE

Fig. 2.



DIE FOR BENDING GIRDER BRACKETS



DROP FORGING AN EYEBOLT. Fig. 3.

tool steel which can be driven into a hot steel block by blows under the power hammer, thus forming the die.

4. As an example of a modified drop forging, the formation of an eyebolt under a power hammer is given. Round bar is used, and is first shaped like *a* on Pl. **11**, Fig. 3, the forging being done in the die, *b*. This die, as well as the other one shown, consists of two blocks of steel fastened together with a spring handle. The inside faces of the blocks are formed to shape the piece as shown. The bar is revolved about 90° between each two blows, and the hammering is continued until the die faces just touch. For the second step, the ball is flattened to about the thickness of the finished eye between the bare hammer dies. The hole is then punched under the hammer with an ordinary punch. The forging is finished with a few blows in the finishing die, *d*, which is so shaped that, when the two parts are together, the hole formed is exactly the shape of the finished forging.

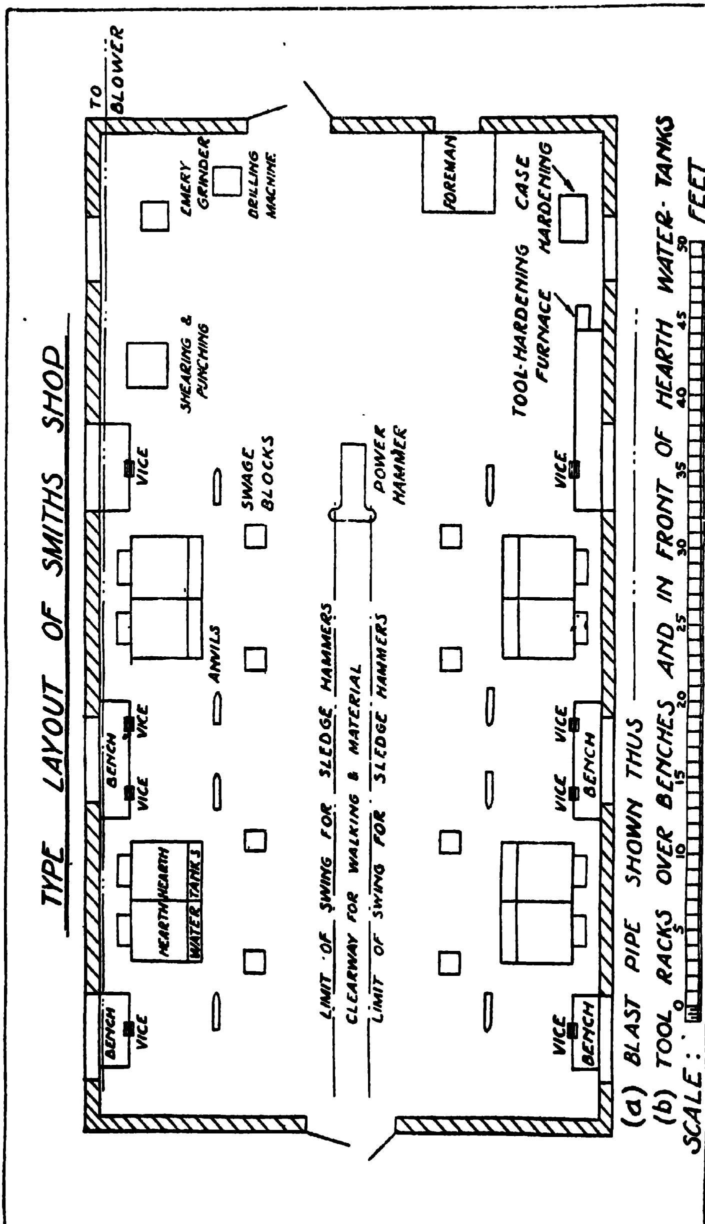
5. Where large numbers of the same article are to be bent to shape, much time will be saved by the adoption of simple jigs or formers, round which to bend the work; this method will, moreover, result in absolute uniformity of the finished pieces, which would be difficult to produce in any other way.

As an example, take a hook, *a*, to fit round the flange of an I beam. Two cast iron blocks, *b*, are cast to shape, and fitted with handles. The iron or steel bar, cut to correct length, is heated up and placed on the lower block. The top block is then hammered into position and the bar is bent to the shape of the *jig; see* Pl. **11**, Fig. 2.

19. *Lay-out of shop*

1. The smiths' shop will normally be used by boilermakers also. The type lay-out, Pl. **12**, shows the most convenient arrangement. The hearths are placed in pairs, and are 2 feet from the side walls to allow room for the main blast pipe, tuyère cooling tanks, &c. With 4-feet square (external) hearths, a distance of 20-feet centre to centre of double hearths is allowed. The smith works with his back to the fire, the beak of the anvil being always on his left. The position of the anvils is as shown. A clear zone 8 feet wide must be left from the anvil outwards to allow for the swing of the striker's sledge hammer. A 2-foot 6-inch way is made down the centre of the shop for traffic. Benches are placed between the forges, and fitted with a standing vice (one between two smiths). Windows light the bench, but are at the back of the smith when not working at the bench; he will, however, get

PLATE 12.


TYPE LAYOUT OF SMITHS SHOP
TO BLOWER
EMERY GRINDER
DRILLING MACHINE
FOREMAN
CASE HARDENING
TOOL-HARDENING FURNACE
SHEARING & PUNCHING
VICE
SWAGE BLOCKS
POWER HAMMER
ANVILS
BENCH
HEARTH
WATER TANKS
LIMIT OF SWING FOR SLEDGE HAMMERS
CLEARWAY FOR WALKING & MATERIAL
LIMIT OF SWING FOR SLEDGE HAMMERS
(a) BLAST PIPE SHOWN THUS
(b) TOOL RACKS OVER BENCHES AND IN FRONT OF HEARTH WATER-TANKS
SCALE: 0 5 10 15 20 25 30 35 40 45 50 FEET

enough light in this case from the opposite windows. Each smith has a tool rack above the benches, on the wall. This arrangement gives a shop with a span of 36 feet. With forges against one wall only, a span of 20 feet should be allowed. The actual arrangement must, of course, depend on circumstances; but the minimum working spaces are given on Pl. **12**, and will serve as a guide in laying out. A power hammer, a drilling machine, a shearing and punching machine, a grinder, a tool-hardening furnace, and a case-hardening furnace are shown. The bending rolls and block will normally be kept outside the shop. Some designers place hearths back to back down the centre of the shop, but this method makes supervision more difficult.

2. A smiths' shop should be well lighted and ventilated. Smoke will normally be discharged by the cowls over the hearths, through separate sheet-iron chimneys, to the outside of the shop; in addition the roof should be provided with louvres or ventilating skylights to lead off the smoke. The floor should be of rammed earth mixed with ashes. The spaces between the forges and at the back of them may be in concrete on which to stand tools, surface plates, vices, &c.

3. **Exhaust fans.**—Instead of using separate chimneys to each fire, it is common practice to carry all the smoke and fumes by means of exhaust piping, to a common chimney, using a fan to induce a draught. This is more effective in clearing the fumes, and gives a clean, well-ventilated shop.

The fan may be either centrifugal or of the propellor type. The former gives a better suction and should be used if the exhaust pipe is long or has many bends. The propellor type requires less power to deal with the same volume, but produces a very small suction; if this type is used, the exhaust piping must be as straight and short as possible.

In any case, the exhaust fans are much larger than the blowers required for the same number of fires, as a much larger volume of air has to be dealt with, though at a lower velocity and, therefore, smaller pressure difference.

The exhaust piping should be approximately equal in cross-section to the sum of the cross-sections of the outlets from the cowls of the fires.

For Bibliography, see page 686.

CHAPTER V

BOILERMAKERS' WORK

20. *The shop, tools and materials*

1. Scope of work.—The work of a R.E. boilermaker will normally be limited to repairs to existing boilers.

He may also be required occasionally to carry out platers' work in the construction and repair of bridge structures.

Under normal service conditions, the boilermakers' shop should be combined with the smithy, under the one foreman; if it is a separate shop, it should be near the smithy, to which boilermakers should have access for any work which requires a forge, an anvil, or smiths' tools.

The repairs to boilers normally include :—

i. Replacement of broken rivets.
ii. Replacement of broken or corroded stays.
iii. Caulking the edges of plates.
iv. Removing, replacing, and expanding boiler tubes.
v. Patching the outside shell of a boiler.
vi. Patching the firebox plates.
vii. Repairing tube plates.
viii. Replacement of extensively damaged plates.
ix. Building up or thickening plates by oxy-acetylene or electric welding.

After any repair work has been executed, a hydraulic test should be applied to the boiler.

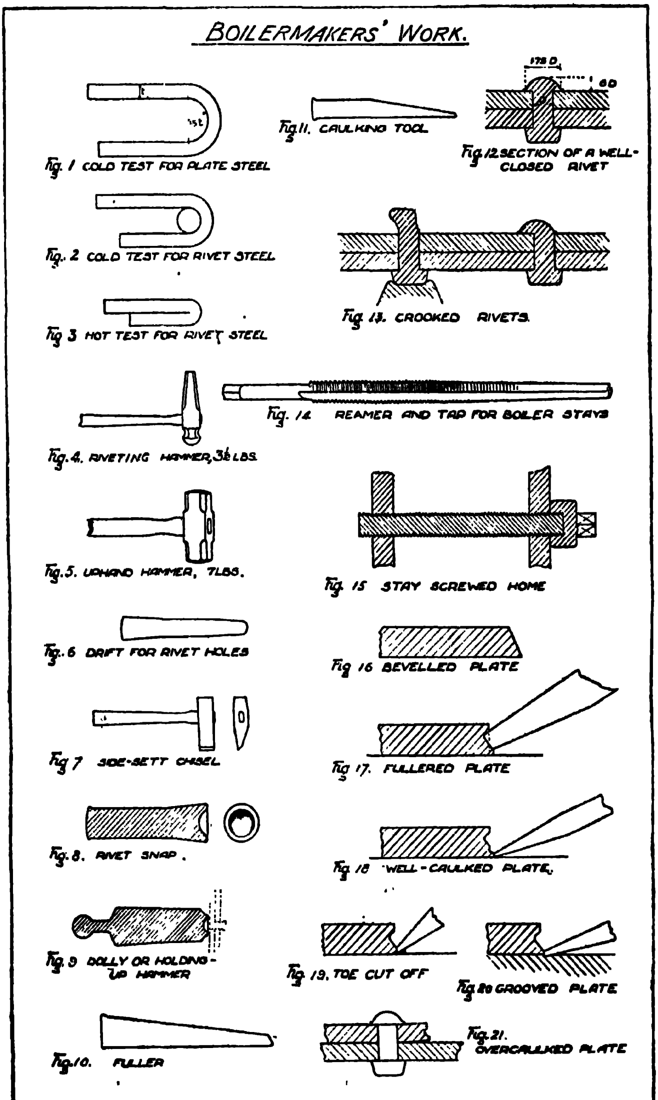
2. Personal tools.—Every boilermaker needs the tools listed in Appendix VI for his own personal use. Some of these tools are expensive, and it is not necessary for each man to have all of them in his tool chest when working in the shop. Those marked with an asterisk would, therefore, usually be kept on shop charge, and would be drawn when required in the shop or when a boilermaker is sent to execute repairs to a boiler outside the shop.

Those tools which are special to the trade are illustrated on Pl. **13**, Figs. 4 to 11. Other tools used are similar to those used by fitters or blacksmiths.

3. Shop equipment.—

i. The equipment must include a supply of those tools given in Appendix VI, which are marked with an asterisk as not normally kept in a boilermaker's chest.

PLATE 13.


BOILERMAKERS' WORK.
Fig. 1 COLD TEST FOR PLATE STEEL
Fig. 2 COLD TEST FOR RIVET STEEL
Fig 3 HOT TEST FOR RIVET STEEL
Fig. 4. RIVETING HAMMER, 3½ LBS.
Fig. 5. UPHAND HAMMER, 7LBS.
Fig. 6 DRIFT FOR RIVET HOLES
Fig 7 SIDE-SETT CHISEL
Fig. 8. RIVET SNAP.
Fig. 9 DOLLY OR HOLDING-UP HAMMER
Fig. 10. FULLER
Fig. 11. CAULKING TOOL
Fig. 12 SECTION OF A WELL-CLOSED RIVET
Fig. 13. CROOKED RIVETS.
Fig. 14 REAMER AND TAP FOR BOILER STAYS
Fig. 15 STAY SCREWED HOME
Fig 16 BEVELLED PLATE
Fig 17. FULLERED PLATE
Fig 18 WELL-CAULKED PLATE.
Fig. 19. TOE CUT OFF
Fig. 20 GROOVED PLATE
Fig. 21. OVERCAULKED PLATE

ii. In addition, a small and mobile shop should contain :—

(*a*) *Forges, field, G.S., Mark IV*, unless combined with a smiths' shop.

(*b*) *Lamps, brazing*, for local heating of plates.

(*c*) *Machines, drilling, hand* (or power driven), capable of drilling up to 1-inch diameter holes in steel.

(*d*) *Machines, drilling, portable, electric*, to drive from the workshop lorry.

iii. Larger shops may be provided with some of the following :—

(*a*) A large cast iron block for flattening and flanging plates.

(*b*) Rolls for bending plates.

(*c*) Compressor and pneumatic drills, and chipping and riveting hammers.

(*d*) A shearing and punching machine.

These are heavy equipment, and cannot easily be carried in a lorry. Their use must, therefore, be confined, as a rule, to base workshops or those served by a railway.

4. **Materials.**—The mild steel which is generally used for boiler repairs should be of the best quality, with a tensile strength of not less than 24 tons and not more than 27 tons per square inch. Its extension before fracture should be not less than 25 per cent. in a length of 8 inches.

The following tests are normally sufficient to show whether steel is suitable or not for use in boiler work :—

The test bar or test strip of plate $1\frac{1}{2}$ inches wide should be heated cherry-red, and quenched in water at about 80° F. The plate strip must then stand bending cold to a curve, the inner radius of which is one and a half times the thickness of the plate, Pl. **13**, Fig. 1.

Rivet steel bar must stand bending double, when cold, over a bar of its own diameter, Pl. **13**, Fig. 2, and when hot till the two shanks touch, Pl. **13**, Fig. 3.

Rivets, steel, boss-head, in sizes rising by sixteenths from $\frac{5}{16}$ to $\frac{3}{4}$ inch in diameter, and *Rivets, steel, countersunk-head*, in sizes of $\frac{1}{4}$, $\frac{5}{16}$, and $\frac{1}{2}$ inch in diameter, are articles of store.

21. *Types of work*

1. **Design of joints.**—In repair work it is generally sufficient to follow the design of the joints already in the boiler, unless these have shown signs of weakness.

For fixing patches, a single riveted lap joint is universally used; the dimensions of the rivets are as follows:—

Diameter of rivet shank $d = 1\frac{1}{2}t$, for plate of normal thickness, or $d = 1{\cdot}2\sqrt{t}$ for exceptionally thick plate.

Rivet holes should be $\frac{1}{16}$ inch larger than the rivet shank, and should have a width of plate at least equal to d between holes, or between any hole and the edge of a plate. All fin or rag at the edge of a hole must be removed, and the strength in shear of the rivet is increased if the edge of the hole is rounded off slightly.

2. **Proportions of rivets.**—The heads of boss-head, or snap-head rivets should be $1{\cdot}75d$ at the base, and $0{\cdot}6d$ thick. Countersunk-head rivets should be $1{\cdot}5d$ at the broadest part, and the depth of the countersink $0{\cdot}5d$.

The length of shank needed is the total thickness of the plates, plus $1\frac{1}{4}d$ for snap-head rivets, or plus d for countersunk-head rivets.

3. **Cutting out rivets.**—To cut out an old rivet, the head should first be cut off, using a sett chisel, Pl. **13**, Fig. 7, and a 7-lb. hammer. The chisel must not be allowed to cut into the plate. If the rivet is still tight, it should be drilled as deep as the thickness of the plate with a drill of diameter $\frac{7}{8}d$. It should then be driven out with a hammer and punch.

A very long rivet may need deeper drilling, especially if it was originally closed hydraulically, a process which makes rivets fit their holes very tightly.

4. **Closing a rivet.**—Before a rivet is closed, a drift should be driven in the hole to ensure that it is fair. A cold rivet should then be tried in the hole to ensure that it is the right size. The rivet should be brought from the forge with the point at welding heat; it is then driven well home, being firmly held up by a *dolly* of sufficient weight while the point is knocked down as quickly as possible, preferably using two hammers, if three men are available. When fairly knocked down, and while still firmly held up, the head should be shaped with a snap.

There should be sufficient metal in the rivet to enable both a complete head the shape of the snap and a small fin to be formed, as shown on Pl. **13**, Fig. 12. The edge of the snap should never be allowed to reach the plate. It is unnecessary to remove the fin.

The concentricity of the head and stem of rivets can be judged by the regularity of their heads. Careless or unskilful riveting may result in irregular spacing or slight staggering of the rivet heads, due to the rivet bending while being closed, as shown on Pl. **13**, Fig. 13.

The main principle of good hot riveting is that the stem of the rivet shall still be quite hot when the work is finished, so that in cooling it will tend to grip the plates firmly together. A loose rivet emits a characteristic dull sound when struck with a hammer.

5. **Replacing stays.**—Both heads of the stay should be cut off and drilled down as described in para. 3. The threads left in the plate can then be picked out with a diamond chisel.

If this work is carefully done, the threads in the plate should be intact. If the threads are badly corroded, or if they have been damaged in drilling or picking out, the hole must be reamered out a larger size, tapped, and an equivalent larger-sized stay fitted.

Threads not appreciably damaged should be trued by being passed through a tap of the same size. Since the pitch of the threads in the firebox and shell plates must be continuous, a long tap must be used, so that its full-sized threads may be still in the plate first threaded while the threads are being started in the other.

Pl. **13**, Fig. 14 shows a reamer and long tap combined. The whole operation of enlarging and tapping both holes consists of passing this tool once right through them. This can be done by hand, or much more expeditiously by means of a pneumatic or electric drilling machine. The new stay should screw home tight enough to require a key to turn it. The key is applied by means of a cap nut, as shown on Pl. **13**, Fig. 15. When in position, the stay should project at both ends about half its diameter as shown. Each end of the stay should now be riveted well down in turn, the other end meanwhile being well held up by means of a heavy dolly. On no account must a stay be struck unless so held up, or the threads will be damaged.

6. **Caulking and fullering.**—The edges of a patch, or of an old plate which leaks at a joint, may be made tight by caulking. This operation must be carefully performed, since much damage may be done by unskilful or careless work. Before a caulking tool is applied, it is essential that the plate should be slightly bevelled. Caulking should never be carried out when the boiler is hot.

In new plate work, the edge should be planed, chipped, or filed, as shown on Pl. **13**, Fig. 16.

Old plates can sometimes be bevelled by chipping, if sufficient metal has been left beyond the rivet holes, but this must not be done if the joint will be weakened thereby. A partial bevel may be given by fullering, as shown on Pl. **13**, Fig. 17.

A fuller may be considered to be a chisel whose edge has been ground off at a slight angle, so that it has one edge slightly acute and one obtuse. All corners and edges should be rounded off. The more acute edge should be applied to the middle of the plate, and a toe formed as shown.

A caulking tool is of the same form as a fuller, but narrower. It should be similarly applied, but nearer the joint, to increase the prominence of the toe. It should then be reversed, with the acute edge downward, and given not more than one or two blows in each place to burr back the toe and seal the joint; Pl. **13**, Fig. 18.

Careless or excessive caulking may produce three bad faults :—

i. If the tool is placed too high, the toe may be cut off, and the work rendered fruitless; Pl. **13**, Fig. 19.

ii. If the tool is driven into the under plate, a groove will be cut, as shown on Pl. **13**, Fig. 20. This weakens the plate and encourages rapid corrosion.

iii. If the tool is correctly placed but is driven too much, the upper plate tends to buckle, as shown (exaggerated) on Pl. **13**, Fig. 21. Thus more harm than good is done, and it will be impossible to caulk the joint again.

7. **Removing boiler tubes.**—The edges of a boiler tube should be carefully driven inwards with a half-round chisel, care being taken not to touch the plate.

The removal of old tubes is facilitated by the use of a tube drawer.

8. **Replacing boiler tubes.**—The ends are most easily expanded in the plate by means of a tube expander, Pl. **14**, Fig. 1. This apparatus is placed with the rollers in the mouth of the tube, and the central spindle is rotated and simultaneously forced in to wedge the rollers farther apart.

To expand small tubes, a set of drifts may be used if no tube expander is available. The drifts should be clean and well oiled. During the operation the other end should be *held up*.

Care should be exercised that the tube is expanded sufficiently to make a tight joint, but not enough to deform the plate. Over-expanding of tubes leads to cracks between the holes in the plate.

Where there is a possibility of the ends of the tubes being burnt, ferrules, either plain or capped, may be fitted, or alternatively the ends of the tubes may be beaded. Ferrules are driven in after the tubes have been expanded. Beading may be done with a hand beading tool or swage or with a beading tool of the type shown in Pl. **14**, Fig. 2.

Tubes should be slightly longer than the outside measurement over the tube plates, so that they may project at each end $\frac{1}{4}$ inch for small tubes, and $\frac{1}{8}$ inch for large tubes which are to be beaded.

9. **Plugging cracks.**—Cracks should be stopped from spreading by drilling and plugging a small hole, nearly clear of the crack at both ends, as shown on Pl. **14**, Fig. 3, after which the crack may be chain plugged, as shown on Pl. **14**, Fig. 4, or otherwise repaired.

10. **Patching a boiler shell.**—

i. The patch must be of sufficient size to provide a good joint on all its edges, and the rivets must be placed in sound undamaged plate of the shell.

ii. The shape of the patch should be decided and chalked upon the boiler. A paper template should then be cut to fit the chalked outline.

The patch, of good soft iron plate or ductile steel, and about two-thirds the thickness of the boiler-shell plate, should be cut to the template, bevelled on all edges, and roughly swaged to fit the curve of the boiler.

iii. The patch should then be held in position against the boiler, and the holes should be carefully marked, keeping a suitable pitch and taking care that sufficient metal is left beyond the holes, both in patch and boiler, to provide ample strength. All the holes should then be drilled in the patch, and two or three holes, far apart, may be drilled in the boiler, using the patch as a template; *see* Pl. **14**, Fig. **5**.

iv. The patch should then be heated in a forge or muffle furnace, applied to the boiler, bolted through the drilled holes, and hammered down quickly to fit snugly all round.

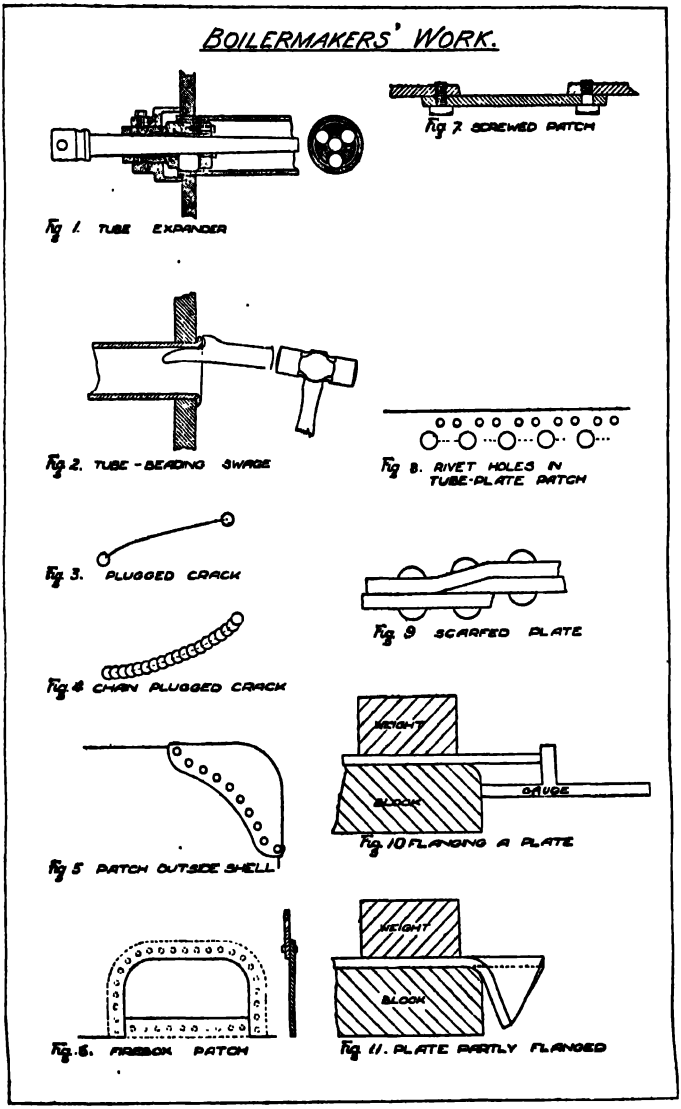
v. The remaining holes should now be drilled in the boiler, after which the patch is taken off again. All burring and sharp edges must be removed, and the surfaces cleaned with sal-ammoniac solution to remove scale.

vi. The patch, while *black hot*, should then be bolted down tight through all holes. One bolt at a time should then be removed and replaced by a rivet, as described in para. 4.

vii. Finally, the patch should be caulked all round.

11. **Firebox patches.**—When patching fireboxes, the old metal beneath the patch should be removed as far as possible, leaving sufficient only around the edges for adequate

PLATE 14.


BOILERMAKERS' WORK.
Fig 1. TUBE EXPANDER
Fig 2. TUBE - BEADING SWAGE
Fig 3. PLUGGED CRACK
Fig 4 CHAIN PLUGGED CRACK
Fig 5 PATCH OUTSIDE SHELL
Fig 6. FIREBOX PATCH
Fig 7 SCREWED PATCH
Fig 8. RIVET HOLES IN TUBE-PLATE PATCH
Fig 9 SCARFED PLATE
WEIGHT
BLOCK
GAUGE
Fig 10 FLANGING A PLATE
WEIGHT
BLOCK
Fig 11. PLATE PARTLY FLANGED

riveting. The object of this is to avoid a double thickness of metal which might result in overheating and consequent troubles.

It is particularly important that no packing or jointing paste of any kind should be used under the patch. Any such jointing would insulate the edges of the patch from the boiler, and so cause the fire to overheat the patch.

12. **Temporary patches.**—Locomotive boilers, and some others, are difficult to patch without removing the firebox, because it is generally impossible to close the rivets, since one side of the plate is generally inaccessible.

When only a small patch is needed, not exceeding two square feet in area, and the patch can be adequately supported by stays, the great expense and loss of time which would be incurred in removing and replacing the firebox is not generally warranted.

Small patches are generally fixed temporarily with setscrews, screwed into tapped holes in the boiler or firebox plate. The setscrews should be smaller in diameter than the normal rivets for the same thickness of plate. A section is shown on Pl. **14,** Fig. 7.

Such patches should be watched carefully; occasionally the setscrews may be tightened up, if necessary, and the edges lightly caulked.

When it becomes necessary to remove the firebox for repairs, the setscrews should be replaced, one at a time, by rivets of correct diameter.

13. **Repair of tube plates.**—If a tube plate shows a tendency to crack extensively, the part affected should be cut out and replaced. The whole plate can only be renewed after removal of the firebox from the boiler. This is seldom necessary if the outside edges and flanges of the plate are still good.

The old plate may be cut out along the outer tube holes, and used as a template for drilling the new plate to take the tubes. The standard overlap of not less than three times the diameter of the rivet must be allowed. This is sometimes difficult when some of the tubes are very near the edge of the old plate. The rivets must in this case be fitted in the metal between tube holes; *see* Pl. **14,** Fig. 8. Rivet holes should be drilled simultaneously through both plates, and bolts placed in a few holes at once and tightened, thus ensuring that the patch does not move while the remainder are being drilled, and that all holes will be fair.

A bolt should then be placed in every hole, the patch well hammered down to make it fit, and the bolts tightened as much as possible.

Each bolt in turn may now be removed, and a rivet closed in its place.

Generally, a patch of this type can only be caulked from inside the boiler. It is advisable to supplement the strength of the patched plate by beading both ends of some or all of the outer tubes.

14. **Corner patches.**—Where a patch must override the joint between two plates, it can only be made watertight by scarfing down the edge of the overriding plate, as shown on Pl. **14**, Fig. **9**.

In the case of an outer-shell patch, tightness may be improved by smearing with a paste, composed of wet sal-ammoniac mixed with fine steel filings or grindings, before the patch is finally applied ; this mixture forms a rust cement.

15. **Fitting new plates.**—Flanging must generally be done by hand, since a press is seldom obtainable under service conditions. The portion of the plate to be flanged should be heated clear red, and placed upon the edge of a cast iron block, the overhang being gauged carefully, as shown on Pl. **14**, Figs. 10 and 11.

A heavy weight should be placed upon the plate, as near the edge as possible, to prevent the centre from hogging or rising up, and the flange quickly bent down a little by rapid blows of wooden mauls. Several re-heats may be necessary before the full degree of flanging is obtained. The greatest possible length of flange should be turned in one heat.

The block should be moulded to the radius of the turn required. In emergency, a heavy timber block may be used, resting upon a stone or concrete floor.

All edges to be caulked should be bevelled, and finally the plate should be well annealed.

16. **Building up by welding.**—The process of welding by oxy-acetylene flame or electric arc may be used in boiler repair work for two purposes.

i. For joining the edges of plates where riveting is difficult or impossible.

ii. For building up the thickness of plates which are locally wasted or grooved.

The work is not usually carried out by a boilermaker, since it constitutes a separate trade. The boiler-shop staff should bear in mind, however, that work which presents great difficulty, and would necessitate long delays if carried out by the patching or renewal of plates, may sometimes be done easily and quickly by welding, if suitable plant and personnel sufficiently acquainted with its use are available.

For Bibliography, see page 686.

CHAPTER VI

HEAT TREATMENT

22. *Introduction*

1. Steel is considered to be an alloy of iron and iron carbide. Whereas pure iron is a soft and ductile metal with a high melting point (1,530° C.), iron carbide is intensely hard and brittle and its addition to iron has the effect of lowering the melting point. When the iron carbide, called " cementite," is in solid solution in the iron, it confers properties of hardness and brittleness upon the resulting steel ; when it is just mixed up with the iron in grains or crystals it makes the resulting product stronger under tensile stress but reasonably soft.

Steel, therefore, can be made hard or soft according as to whether the cementite of its composition is in solution or just mechanically mixed with the iron, and its condition can be controlled by " Heat Treatment."

In all heat treatment operations the temperature must be very accurately controlled, especially in the case of modern alloy steels.

2. **Critical range.**—When steel is heated, the temperature at which the cementite goes into solid solution is called the *upper critical temperature or point of decalescence.* Upper critical temperatures are given in Table F, page 79.

The temperature at which the cementite comes out of solution again on cooling is called the *lower critical temperature or recalescence point.* The interval between these two temperatures (about 30° C. for commercial plain carbon steels) is called the *critical range.* Owing to the latent heat of fusion, the temperature remains approximately constant for several minutes at both ends of the critical range, hence the names decalescence and recalescence. The greater the carbon content the lower the temperature.

23. *Hardening*

1. If the steel is to remain hard when it has cooled down, the cementite must be kept from coming out of solution in the iron. This can be effected by cooling the steel so quickly through the critical range that there is no time for the change to take place. The rate of cooling determines the degree of hardness.

The process of hardening consists in heating the steel slowly and uniformly up to a point slightly above the upper critical temperature (*see* Table F), and quenching it suddenly in some cooling medium. In the case of carbon steels, hardening by this method is only effective when the percentage of carbon lies between 0·2 and 2·0 per cent. The extent to which hardening occurs increases with the proportion of carbon in the metal.

2. The temperature for hardening common articles of carbon steel can be roughly gauged by the brightness of the heated metal (*see* Table D), but for the proper heat treatment of special steels this method is not sufficiently accurate. In this case a pyrometer should be used, and the maker's instructions strictly followed.

TABLE D.—*Various colours and temperatures of steel when heated*

Colour	Temperature	
	°C.	°F.
Just visible red	500 to 600	932 to 1,112
Dull cherry-red	700 to 750	1,292 to 1,382
Cherry-red	750 to 825	1,382 to 1,517
Bright cherry-red	825 to 875	1,517 to 1,607
Brightest red	900 to 950	1,652 to 1,742
Orange	950 to 1,000	1,742 to 1,832
Light orange	1,000 to 1,050	1,832 to 1,922
Lemon	1,100 to 1,200	2,012 to 2,192
White	1,200 to 1,300	2,192 to 2,372

If during the hardening process the metal is heated above the upper critical temperature, the grain tends to become coarse, and this reduces the strength. In practice, as a rapid cooling sets in immediately the steel leaves the furnace, the article must be heated slightly above the critical temperature, and quenched before it cools below the critical temperature and returns to its former state.

3. Although small articles such as chisels can be hardened satisfactorily by heating in a forge and quenching, modern practice is to heat the article uniformly in a muffle furnace, such as that shown in Pl. **10**, Fig. 18, fitted with a pyrometer. In a properly constructed electric, gas or oil-heated furnace the temperature can be very closely regulated.

It should be noted that mild steel (up to 0·2 per cent. carbon) cannot be hardened in this way.

The usual quenching baths are water, oil, or brine, other substances being used for special purposes. Brine will absorb

heat quicker than water, and water quicker than oils. Quenching in brine therefore gives the maximum hardness, but it should be remembered that very rapid cooling may result in uneven contraction, producing surface cracks.

The choice of the quenching bath will depend upon the composition of the steel and the shape of the article. Clear cold water, free from oil and grease, is commonly used for ordinary carbon steels. Brine may be substituted when additional hardness is required. Sperm or lard oil are commonly used for springs, and raw linseed oil is excellent for cutters and other small tools. In the case of repetition work, care must be taken to keep the bath at a constant temperature.

24. *Tempering or drawing*

1. When a piece of carbon steel has been hardened by quenching in water it is glass hard and very brittle, owing to the complete fixation of the cementite. Metal in this state is useless for cutting tools, and some of this hardness has to be sacrificed to obtain toughness, by letting some of the cementite out of solution. This is effected by re-heating to a temperature *well below* the critical temperature followed by any rate of cooling. Re-heating temperatures for various articles are shown in Table **E**.

Given suitable quenching media it is possible to produce the correct degree of toughness during the hardening operation itself, but the special fluids required for this purpose are not usually available in the service.

2. In practice, tempering may be carried out in one of the following ways :—

i. *Point tempering.*—In this process, hardening and tempering are combined in one heat. The part to be treated is raised above the upper critical temperature, after which the point or cutting edge only is quenched. The point is then quickly polished to a bright surface with a stone. The heat in the body of the tool returns by conduction to the point, which is re-heated, and coloured oxide films appear on the polished point. From these colours, the temperature of the metal can be estimated (*see* Table C). When the colour corresponding to the required temperature is obtained, the whole tool is quenched.

ii. *Hot plate tempering.*—In this method, the hardened article is laid on a hot metal plate and re-heated by conduction to the required temperature. As before, the temperature can be estimated by the colour of the oxide layer.

TABLE E.—*Details for tempering tool steel for various purposes*

Oxide tint	Temperature °C.	Temperature °F.	Uses of steel	Tempering bath Lead	Tempering bath Tin
Pale yellow ..	220	428	Small edge tools; small lathe, planing, and slotting tools.	7½	
Straw ..	230	446	Razors and surgical instruments.	8½	
Golden yellow	243	470	Penknives, hammers, taps, and reamers; large lathe, planing, and slotting tools; small drills; dies, miners' drills, chasers, rimers, plane irons, wood-borers, and scrapers.	10	
Brown ..	254	490	Scissors, shears, cold chisels, large drills, shear blades, punches, and wood-cutting tools.	14	
Brown dappled with purple	266	510	Axes, planes, and wood-working tools; lathe tools for copper.	19	
Purple ..	277	530	Table knives, large shears, wood-turning tools, and cold chisels for soft iron and brass.	30	
Blue	288	550	Swords, coiled springs, augers, boilermakers' snaps, firmer chisels, smiths' tools, cold sets, laminated springs, and fine saw-blades.	48	
Dark blue ..	299	570	Hand saws and screw drivers.	50	2
Pale blue ..	316	600	Too soft for tools ..	Boiling linseed oil.	
Just visible red in the dark	500	932	Big spiral springs ..		

iii. *Lead alloy bath tempering.*—The steel to be tempered is heated in a bath of molten lead alloy, the melting point of which corresponds to the tempering temperature required. As soon as a uniform temperature has been reached, the article is taken out and allowed to cool.

The advantage of this method is the uniformity of heating obtained.

iv. *Sand bath tempering.*—The sand bath is another common method of tempering for small work, the sand being heated in an iron container with an open top. By this method a piece to be tempered, *e.g.* a punch, can be given different tempers throughout its length, by placing the article vertically in the sand.

25. *Normalizing and annealing*

1. The operations of casting, forging, welding, rolling, stamping, wire-drawing, &c., make steel hard and brittle and set up internal strains.

The process of relieving these strains and rendering the steel soft and ductile is called *normalizing* or *annealing.* These terms are somewhat loosely used but they are accurately defined as follows :—

i. *Normalizing* means heating the steel above the critical range and then allowing it to cool slowly in still air at ordinary atmospheric temperature.

   The upper critical temperature must not be exceeded by more than 40° C. or so and the heating should last 15 minutes or more depending upon the size and shape of the article.

ii. *Annealing* means heating as for normalizing but cooling *very slowly* (for 24 hours or more) in the furnace (with the heat shut off).

In both cases the cementite comes out of solution, the crystalline structure is refined, the metal is softened and internal strains are removed.

The difference is merely one of degree, the process being more complete with annealing than with normalizing.

If facilities exist, slow cooling in the furnace is always preferable for the lower carbon steels used in structural work where strength test requirements are most important, but if an article has not to be machined or otherwise worked, air cooling will suffice in many cases.

As a compromise, in cases where the heating is done in a smith's hearth, the article may be embedded in lime or ashes to lessen the rate of cooling.

2. In the absence of precise information the following Table F, may be used as a guide when annealing plain carbon steels.

TABLE F.—*Annealing temperatures for plain carbon steels*

Percentage of carbon	Upper critical temperature		Normalizing or annealing temperature	
	° C.	° F.	° C.	° F.
0·12	880	1,620	895–910	1,640–1,670
0·2	845	1,550	855–870	1,570–1,600
0·3	810	1,490	820–835	1,510–1,540
0·4	775	1,430	800–815	1,470–1,500
0·5	765	1,410	775–795	1,430–1,460
0·6	755	1,390	765–775	1,410–1,430
0·7	745	1,370	750–765	1,380–1,410
0·8	740	1,360		
0·9 and above	730	1,350		

In high carbon steels (0·7 per cent. carbon and above) the presence of a large proportion of cementite renders them difficult to machine even when fully annealed as above. It is, therefore, usual first to normalize them and then to subject them to a prolonged (several hours) heating at about 700° C., just below the lower critical temperature. This latter process is sometimes known as *spheroidizing* since it breaks up the grains of the cementite iron mixture into globules or " spheroids " in which condition the steel is much softer and therefore easier to machine.

26. *Case hardening*

1. It was observed in Sec. **23**, para. 3, that mild steel contains too low a percentage of carbon to be hardened, also that hardened carbon steel lacks toughness.

If it is desired to produce articles having the toughness of mild steel and a hardened surface (*e.g.* cam shafts and gudgeon pins) some method of case hardening must be used.

The following process, which applies to mild steel, wrought iron, and alloy steels of low carbon content, may be divided into :—

i. *Carburizing*, which means converting the outside of a mild steel, &c., bar to high carbon steel by direct absorption of carbon. It is carried out by heating the steel to redness in contact with some substance rich in carbon, or one that will give off carbon monoxide.

This results in a mild steel or wrought iron core having a skin of high carbon steel.

ii. Subsequent heat treatment to obtain the qualities desired.

2. Carburizing is usually carried out by packing the articles together with bone dust, charcoal, or some case-hardening compound (*e.g.* "Kasenit") in iron boxes rendered air tight by luting the lid with clay. The parts must be cleaned before packing, and should be so packed that they are completely surrounded with compound, not touching each other or the side of the box. Test-pieces should be included, one at each end of the box, so that the depth of case can be ascertained by fracture. The box is heated to about 900° C. in a muffle furnace, and the time of "soaking" depends on the depth of case required. A box 12 in. by 12 in. by 6 in. containing mild steel shafts $1\frac{1}{2}$ in. in diameter would produce a case approximately $\frac{1}{16}$-in. thick in 6 hours.

On removal of the box from the furnace, it should be allowed to cool, after which the lid is unsealed. Heat treatment is now necessary because the prolonged soaking at bright red heat will have caused the grain of both the core and the case to grow into large crystals. The refining is carried out in two operations, *viz.* :—

i. *To refine the core.*—Re-heat in an open muffle to the upper critical temperature of the core (870–880° C.) and quench in oil.

ii. *To refine the case.*—Re-heat to the upper critical temperature of the case (760–780° C.) and quench in oil or water to harden it. Water will give the greater hardness but involves the greater risk of distortion.

This second heating is necessary because the case, having a higher percentage of carbon than the core, will therefore have a lower critical temperature and the first operation will have left the case in a coarse grained condition.

If the first quenching be in oil and the second in water, the part should be thoroughly freed from oil before the second re-heat, otherwise soft spots on the surface may result.

3. A thin case may be produced quickly by the prussiate of potash method. Yellow prussiate of potash crystals are melted in a cast iron pot in the fire, and the article is immersed in it and the whole kept at a red heat for about 75 minutes depending on the depth of case required. The article may then be quenched immediately, or re-heated and quenched as before.

4. The effects of case hardening can be localized by the following methods :—

i. *Plating method.*—Before carburizing, the article is copper or nickel plated, and the plating removed from the surface to be hardened.

ii. *Coating the portions which are to remain soft with asbestos or fireclay.*

This method is not so reliable as the plating method.

27. *Alloy steels*

1. Small percentages of other metals are added to steels to improve their properties and facilitate heat treatment. Such steels are expensive, and to get the full value out of them it is essential that they should be subjected to the correct heat treatment, which varies according to their composition but is clearly laid down by the makers.

2. **High-speed tool steels.**—High-speed tool steel is an alloy of steel with tungsten and chromium and it has the following characteristics :—

i. It is self-hardening.
ii. It is hard when red hot.

A normal composition is 19 per cent. tungsten, 5 per cent. chromium and 0·67 per cent. carbon.

High-speed steel can be distinguished from carbon steel by the dull red spark which it gives off when ground on an emery wheel. Carbon steel gives a brilliant white spark.

High-speed steel is usually supplied in the annealed condition together with instructions for heat treatment; in the absence of such instructions the following procedure is recommended :—

Forge to shape at a bright red heat (never less than about 845° C.), using a heavy hammer and working as quickly as possible. It must be borne in mind that this material is very liable to crack through blows or sudden changes of temperature.

To harden, heat up the whole tool gradually and evenly to about 855° C., and then rapidly heat up the point of the tool to about 1,300° C. or until it appears to be on the point of fusing. Then cool in a blast of *dry* cold air or in whale oil. Water or even damp air may produce cracks.

Tempering is only necessary in the case of tools with slender edges, or when it is required to produce a smoother finish on a fairly soft steel.

Re-heating is necessary, and makers' instructions should be followed.

Grinding of high-speed tools must be carried out with care as any undue heating may cause cracks.

3. **High-speed steel tips for machine tools.**—Owing to the high cost of high-speed tool steel, considerable economy can be effected by using lathe, &c., tools consisting of a shank of either mild steel or medium carbon steel, such as No. 3 temper carbon steel, with a high-speed steel tip brazed on.

Mild steel can be used if the section is sufficiently large, but may bend if over-stressed.

The shank is forged and ground to the shape of the tool, with the tip ground down to about half depth or rather less for a distance of about one inch, forming a seating for the tip; the surfaces of the seating being ground smooth and flat; the re-entrant angle may be radiused to improve the seating, though this is not essential.

The tip is cut off to length from bar machined on the surfaces which will bed on the seat, the edge connecting these surfaces being radiused to fit. The tip should be slightly wider than the seat.

The tip is then laid on the seat with a layer of about $\frac{1}{32}$ of an inch of brazing compound in between and may be bound on with wire, though this is unnecessary in most cases. A suitable brazing compound is Super Welding Brazing Alloy (supplied by Alfred Herbert, Coventry).

The tool is heated to red heat, the tip pressed or hammered down on to the seat, and then given the heat treatment (hardening and tempering) necessary for the particular type of high speed steel of which the tip is made.

Pressing home the tip may often be done at the hardening temperature instead of at a red heat.

The tip may then be ground to shape, using plenty of coolant to prevent the formation of surface cracks.

4. **Nitralloy.**—This aluminium-chromium alloy, briefly referred to in Chap. I, is case hardened by the absorption of nitrogen from ammonia gas. The surface obtained is much harder than anything previously known in metallurgy. It will cut glass or even quartz and cannot be touched with special testing files. The Brinell figure is from 900 to 1,100, which is about double that obtained with ordinary nickel-chrome case-hardened steel.

The nitration process is carried out in an electric furnace at a temperature of 500° C. for a period of 90 hours or less according to the depth of case required.

Apart from the extreme hardness obtained the great advantage of the process is that it requires a comparatively low temperature which obviates distortion, even with pieces of intricate design. In particular, crankshaft journals may be case hardened and **duralumin** connecting rods can be run direct on to nitralloy crank pins without anti-friction linings.

Nitralloy steel retains its hardness up to 600° C., whereas other steels hardened by quenching begin to lose hardness at 180–200° C.

For Bibliography, see page 686.

CHAPTER VII

SOLDERING, BRAZING AND WELDING

28. *Introduction*

Soldering, brazing and welding are different methods of joining metal parts to others of the same or of different kinds.

The processes of soldering and brazing differ from that of welding; in the former the jointing is effected by an alloy known as "solder" or "spelter" having a lower melting point than the metals joined, while in the latter the metal used for the joint is the same as that of the parts joined. This second form of joint is called an *autogenous* joint or weld.

The essential for a strong joint made by either method is actual metallic contact at the joint surfaces. Before a joint is made, the surfaces to be joined must be clean, bright, and free from any oil, grease or oxides. Metallic oxides invariably form when the surfaces to be joined are heated up, and these must be removed by means of fluxes. These fluxes are placed on the surfaces of the heated joint, melt, and then pick up the metallic oxides as they form. The oxides float on the liquid flux and the actual surfaces of the joints are thus kept clean, so that an alloying action can take place, or so that the actual fused joint free from oxide can be formed.

The solders, spelters and fluxes in most common use are given in Table **G**, and some melting points which will be found useful in soldering and brazing are given in Table **H**.

29. *Soldering*

1. **Soft soldering.**—Soft soldering is usually done with a copper soldering *iron* or *bit* (*see* Pl. **16A**, Fig. 1); the bit is of copper, since this metal is a good conductor of heat. Owing to the fact that a copper bit readily oxidizes, and that the film of oxide so formed is a bad conductor of heat, it is necessary to coat the nose of a hot bit with soft solder or tin. This operation is called *tinning* the bit. The tin on the bit does not oxidize nearly so quickly as the copper forming the bit, and, therefore, the heat of the bit is not insulated by the non-conducting oxide.

To tin the bit, first heat it to below red heat, clean the nose with a file and rub it in some suitable flux, such as sal-ammoniac, and then let the solder melt over the nose.

It is important not to overheat the soldering iron. This must be kept well below a red heat or the tin will be burnt

TABLE G.—*Particulars of various kinds of soldering, composition of solders, fluxes, and metals joined*

Description of soldering	Composition of solder	Metals joined	Fluxes
Soft soldering	Tinman's solder:— 35 per cent. to 50 per cent. lead. 65 per cent. to 50 per cent. tin. The lesser lead percentage is known as fine solder, the higher lead percentage is known as coarse solder. Plumber's solder :— 65 per cent. to 75 per cent. lead. 35 per cent. to 25 per cent. tin.	Tin - plate, zinc, copper, brass, and iron.	Zinc chloride, resin, and sal-ammoniac. Ammonium chloride is a good flux for joining copper and iron, dilute hydrochloric acid for zinc and zinc-coated articles, and Russian tallow for heavy lead-work.
Silver soldering	Solder for general work :— Copper, 43 per cent. Silver, 9 per cent. Zinc, 48 per cent. Solder for thin sheets of mild steel :— Copper, 90 per cent. to 95 per cent. Silver, 10 per cent. to 5 per cent. Solder for small brass work :— Copper, 50 per cent. Silver, 30 per cent. Zinc, 20 per cent.	Gold, silver, copper, iron, and alloys of these metals.	Borax or, for very hard solders, powdered glass. Solder filings may be mixed with borax.

TABLE G.—*continued*

Description of soldering	Composition of solder	Metals joined	Fluxes
Hard soldering, or brazing	Spelter or brass for general iron-work :— Zinc, 35 per cent. Copper, 65 per cent. For brazing copper :— Zinc, 40 per cent. Copper, 60 per cent. White spelter :— Copper, 35 per cent. Zinc, 57 per cent. Nickel, 8 per cent.	Brass, copper, iron, and steel.	Borax with powdered spelter, or borax alone. Acid fluxes should not be used on electrical work.

TABLE H.—*Melting points of some metals and alloys*

	° F.	° C.
1. Fine solder	334	170
2. Tinman's solder	374	190
3. Plumber's solder	437	225
4. Tin	446	230
5. Lead	626	330
6. Zinc	788	420
7. Silver solder (copper 43 per cent., silver 9 per cent., zinc 48 per cent.)	1,580	860
8. Spelter (copper 60 per cent., zinc 40 per cent.)	1,652	900
9. Spelter (copper 65 per cent., zinc 35 per cent.)	1,679	915
10. Silver	1,760	960
11. Brass (copper 67 per cent., zinc 33 per cent.)	1,778	970
12. Silver solder (copper 90 per cent., silver 10 per cent.)	1,886	1,030
13. Cast iron	2,192	1,200
14. Mild steel	2,732	1,500

off the nose of the bit, oxides will form, and the bit will require to be re-tinned.

The surfaces of the pieces to be joined must be thoroughly cleaned, tinned, and then securely fixed. They must then be neatly coated with flux where the solder is required to run, and placed together. The tinned bit is then held against the work till the latter is well heated. A drop of molten solder is then allowed to come off the bit and will spread over the joint where the flux has been placed. Then draw the bit along the joint to make the solder run where it is wanted. A stick of solder held against the hot bit keeps up the supply of molten solder on the joint.

Always work the molten solder down hill.

On completion of work, all traces of flux, especially acid flux, must be carefully removed.

2. **Hard soldering or brazing.**—As with soft soldering the secret of successful brazing is the thorough cleaning of the parts to be joined. The solder or spelter is applied in the form of rod or filings. The filings must not be too fine or they will be oxidized before they are able to flow as molten metal to the joint. Moistened borax must be freely applied to the solder and to the joint. The parts to be brazed are given a coat of borax paste, clamped or bound together and placed on the hearth surrounded with firebrick, charcoal, or other non-conducting material to reduce the rate of cooling during the brazing operation.

The whole joint is then heated to a bright cherry-red by a paraffin blow lamp or by a gas blow pipe. Experience is necessary to judge the correct temperature, and care must be taken not to melt the parts being joined. This remark applies particularly to brass which has a melting point not greatly exceeding that of the spelter. When the correct temperature is reached a mixture of borax and spelter is applied to the joint. The spelter melts and permeates the joint, forming a hard soldered or brazed junction. When the borax is allowed to remain on the work until it is cold it will be found to be glassy and difficult to remove. Some common salt thrown on to the work just after the spelter sets will obviate this trouble.

3. **Silver soldering.**—Silver soldering is akin to brazing and is carried out in much the same manner. The melting point of most silver solders is a little lower than that of spelter, and the operation is somewhat easier to carry out than brazing. A silver soldered joint, however, is not so strong as a brazed one. The most economical method of applying the silver solder is to cut off a narrow strip and fix it in the end of a thin iron rod slotted at the end. When working with thin brass,

great care must be exercised not to overheat the joint, as the temperature required to melt the silver solder is only a little less than that required to melt the brass.

4. **Strength of joints.**—A joint made by soft soldering is the weakest, and is only used for small work. A joint made by silver soldering is intermediate in strength between soft soldering and brazing, but is easier to work than a brazed joint. A joint made by brazing, or hard soldering, is the strongest.

5. **Typical examples of soldering and brazing work.**

i. *Soft soldering.*	Seams in lead pipe. Tubes in a motor-car radiator. Joint in electric wire.
ii. *Silver soldering.*	Joint in shank of brass key. New tooth in brass gear wheel. Brass nipples to copper tubes.
iii. *Brazing.*	Parts of bicycle frame. Pipe joints subject to vibration.

6. **Working temperature of joints.**—It will be clear that the working temperature also affects the choice of method. If a temperature exceeding (say) 150° C. (300° F.) is likely to to be reached when the joint is in use, it must be either silver soldered or brazed.

30. *Re-lining white metal bearings*

1. White metal bearings are commonly used for high-speed shafts, especially if of fairly large diameter. They are almost universal for the main bearings, and common practice for the big-end bearings, of modern internal combustion engines. Though unable to withstand the pressures and temperatures for which bronze bearings are suitable, they have several advantages; friction is less, the soft, almost fluid nature of the metal enables it to adapt itself to the journal more closely, and if a bearing does run hot, the metal melts and runs, but is too soft to damage the shaft as a bronze bearing would.

2. White metal bearings are usually carried in a shell, in two halves, made of cast iron, cast steel, or bronze. This shell is lined with the white metal, which is poured in in the molten state, as described below.

3. **White metals** are alloys of widely varying composition, the principal constituents being tin, lead, copper and antimony. For high-speed work, an alloy containing 80 per cent. of tin and no lead may be used, while for low-speed work 60 per cent. of lead and 20 per cent. of tin is suitable. There are many proprietary brands, and any of the makers of repute

will supply a metal suitable for a given purpose. The mixing of the metals is not work for the military engineer.

Metal from old bearings should not be used again.

4. **Preparing the shells for re-metalling.**—The shells must first be cleaned thoroughly with the help of a blow-lamp, all old metal, oxides, and grease being removed. Cast iron and steel shells may require "pickling" in hot caustic soda solution. The parts which are not required to take the metal are then whitewashed or coated with blacklead, and the shell is heated, preferably in an oven, or, if not too large, by immersion in a bath of molten tin; failing an oven or a large enough bath, it may be heated by means of blow-lamps applied to the outside of the shell, but it is not easy to get uniform heating by this means. The shell should be heated to a temperature sufficient to melt tin (240° C.).

The shell should then immediately be brushed over with flux (killed spirits of salts, Fluxite, or other proprietary flux) and tinned with pure tin. The tinning is best carried out by dipping again in the tin bath for a few seconds; if this is impracticable, it can be tinned with an iron, keeping the shell hot by a blow-lamp applied to the outside.

The tinning must be thorough and complete; any bare spots are liable to result in a ruined bearing. It may be necessary to dip the shell again. Cast iron shells must be tinned quickly.

Immediately after tinning, the bearing should be wiped out with a clean rag to remove all flux and surplus tin, and then given a light coating of tin without flux.

5. **Running in the metal.**—The halves of the bearing are clamped to a mandrel (a piece of steel shaft or piping) about $\frac{1}{8}$ to $\frac{1}{4}$ in. smaller in diameter than the journal, with two pieces of steel plate between the faces (*see* Pl. **15**). These plates should be coated with black lead. The whole is then placed on a face plate and sand or clay packed round the bottom of the shells to prevent the metal from running out.

Pre-heating of the jig is most essential before filling.

The metal should, if possible, be run in immediately after tinning, without allowing the shell to cool. If allowed to cool it must be heated again before pouring, but this is likely to lead to oxidation. The running temperature of the metal depends upon its composition, but is usually from 300° to 330° C. (*not higher* or the metal will be damaged). The metal should be stirred frequently during the heating operation.

The molten metal should be poured in as quickly as possible, running the ladle round the opening, to keep the head of metal equal on both sides. A wire should be worked up and down in the metal to aid the escape of gas and air. As the metal

PLATE 15.

REMETALLING WHITEMETAL BEARINGS

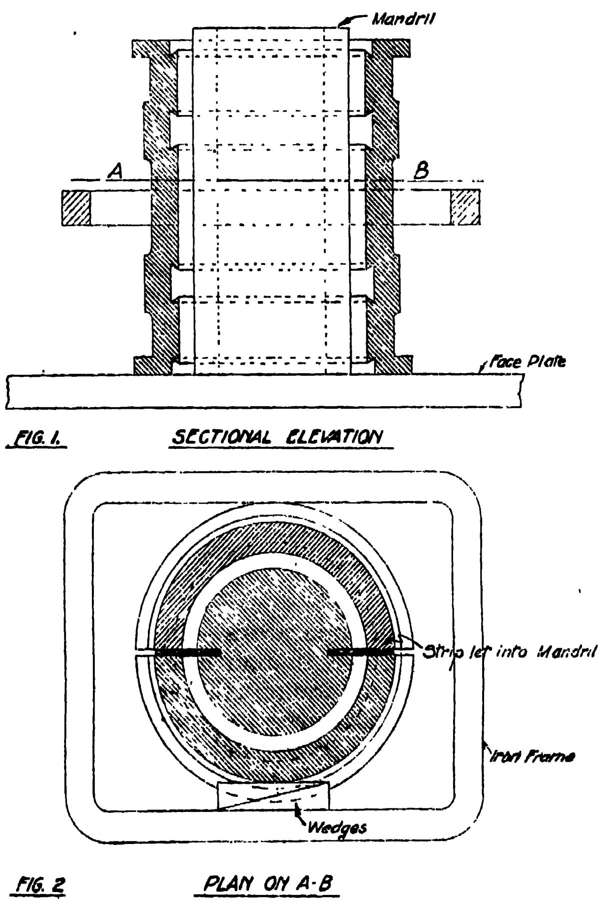


FIG. 1. SECTIONAL ELEVATION

FIG. 2 PLAN ON A-B

cools and contracts, it will be found possible to add a little more. When in a pasty condition, it should be pressed down into the shell with a piece of wood.

6. **Finishing the bearing.**—When cool, the bearing is removed from the mandrel, the two halves are clamped together (with shims, if fitted, between them, as in the engine) and machined on a lathe to a tight fit in the journal, and finally scraped in to a running fit, as described in Sec. **37**, para. 9.

31. *Welding by gas and electricity*

1. Welding is of great use, both in production and repair work, but the success of the welded joint depends mainly upon the integrity and skill of the operator. The ease with which a bad weld can be effected and the great difficulty of determining by its appearance whether it is sound or not, constitutes a danger. Well-trained operators are therefore essential, particularly for repair work, and adequate manual dexterity can only be maintained by constant practice.

Among the numerous applications of welding are the following: filling up blow-holes in castings; repairing cracked cylinders and water jackets; building up worn shafts, gear wheel teeth, &c.; repairing boilers, pipes, girders, &c., *in situ*; restoring incorrectly machined parts; making large steel tanks where riveted joints would otherwise be used, thus effecting a great saving of time; "fabricating" the stators of electrical machines, engine frames, &c.

There are two distinct types of welding, *viz.*: *gas welding* and *electric welding*.

2. **Protection of operators.**—In both systems the operator must be protected from ultra-violet and infra-red rays, heat and glare, and from particles of hot metal.

The eyes in particular must be protected by using goggles or a screen with tinted glasses, but in heavy welding and in cutting work it is desirable to use fireproof gauntlets and aprons as well.

The best protection from the oxy-acetylene flame is afforded by *yellowish-green* or *sage-green* glass of as dark a shade as the operator can work with. *These glasses, however, are not sufficient protection for electric arc welding* for which two superimposed glasses are required, one *dark ruby* and the other *green*, the latter being on the eye side of the goggles or screen. In all cases a clear glass should be added on the work side to prevent splashes of molten metal from damaging the more expensive tinted glasses. In electric arc welding where one hand only is required for the actual welding operation, it is usual to use a welding screen with correctly coloured

glasses instead of goggles. When welding is carried out in the vicinity of other workmen it is also advisable to use some form of screen to isolate the welding.

3. **Fuel gases.**—In gas welding either hydrogen, coal or acetylene gas may be used as fuel, but for various reasons acetylene is the most convenient for service purposes. Some particulars of these gases are given in the following table :—

Gas	Approx. calorific value B.Th.U. per cubic foot	Flame temperature	
		With air	With oxygen
		° C.	° C.
Coal ..	550	1,600	2,000
Hydrogen	290	1,700	2,300
Acetylene	1,450	2,300	3,500

(The temperature reached with the electric arc exceeds 4,000° C.)

No great precision can be claimed for these figures, but relatively they are approximately correct.

32. *Oxy-acetylene welding*

1. There are two main systems of oxy-acetylene welding, one the *low pressure* system, in which acetylene is generated locally from calcium carbide, and the other the *high pressure* system, which uses factory made acetylene supplied in steel cylinders.

2. **Oxygen supply.**—In both systems the oxygen is supplied in steel cylinders, the most common standard size containing 100 cubic feet of free gas compressed to a pressure of 120 atmospheres (1,800 lb./sq. in. approx.). The approximate weight of this size of cylinder is 118 lb., the diameter 7 in. and the length 53 in. The contents can be roughly gauged from the indicated pressure, *e.g.* if the pressure is 50 atmospheres the contents will be about $100 \times \frac{50}{120}$ = 42 cubic feet.

The pressure is reduced to a value within the control of the blow-pipe tap by passing through a regulator screwed to the cylinder.

Pl. **16B**, Fig. 1, shows a typical modern oxygen regulator as supplied by the British Oxygen Company. No low pressure gauge is fitted but 6 regulator settings are provided, marked 1 to 6, suitable for passing hourly 150, 500, 1,000, 1,500,

2,000 and 2,500 litres of gas respectively at the pressures indicated in Table I.

Having set the regulator to suit the blow-pipe tip in use, the operator makes the final adjustment at the blow-pipe tap.

Fittings for *oxygen* cylinders have *right-handed threads* and are *painted black*.

3. **Acetylene supply**.—i. *Low-pressure system*.—The working principle of the acetylene generator is the same as that of an ordinary acetylene lamp. An outline of a large generator, together with all auxiliary plant, is illustrated in Pl. **16**. For successful welding the supply of acetylene should be slow and regular, otherwise the heat generated by the chemical action will be excessive. Usually a gallon of water is allowed per pound of carbide, and this yields about 4·8 cubic feet of free acetylene at a pressure of 7 to 10 in. of water.

Acetylene generated from commercial carbide must be purified before being used for welding. Solid particles are removed by passing the gas through some porous material, *e.g.* cotton wool or felt. Chemical impurities such as ammonia and sulphur compounds are absorbed by passing through a purifier filled with *Heratol* or other purifying compound. Heratol is a solution of chromic acid absorbed in porous earth. It is strongly acid and must be handled carefully. One pound of Heratol will purify 110 cubic feet of acetylene.

Care must always be exercised in handling acetylene plant. The gas is explosive and poisonous; good ventilation is therefore essential. Copper pipework must not be used as copper forms with acetylene an explosive compound which detonates when subjected to shock.

To avoid *flash-back* an hydraulic back pressure valve is invariably placed in the pipe line between the acetylene gas-holder and the blow-pipe. The object of this is to prevent the oxygen from blowing back into the gas-holder and producing an explosive mixture if the blow-pipe tip should become blocked. Pl. **16A**, Figs. *3a* and *3b* show the details of an hydraulic valve. If the blow-pipe becomes stopped up, the oxygen comes back through the acetylene pipe, *c*, by overcoming the forward acetylene pressure from the gas-holder. On reaching the body of the valve, *d*, the oxygen blows the water out of the tube, *a*, and so escapes to the atmosphere; at the same time water is forced up the pipe, *e*, and so seals the acetylene pipe from the gas-holder. Every time the plant is used the tap, *f*, should be opened to ascertain whether the water level in valve is correct.

Water required to fill up to the proper level is poured in through the pipe, *a*.

PLATE 16.

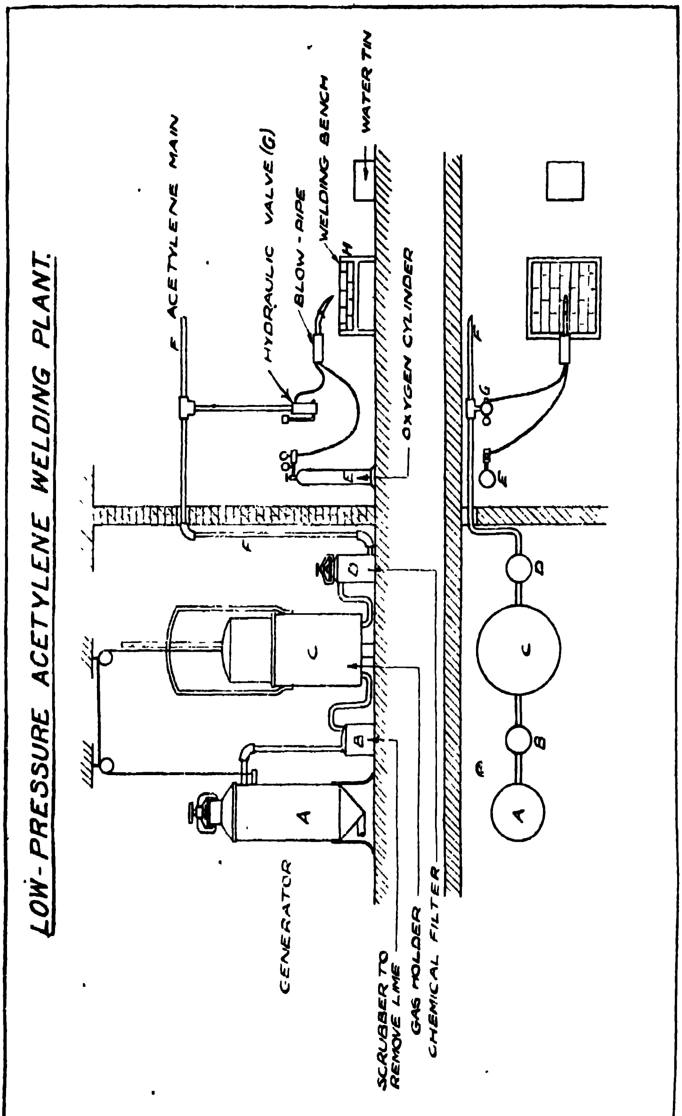

LOW-PRESSURE ACETYLENE WELDING PLANT.
F ACETYLENE MAIN
HYDRAULIC VALVE (G)
BLOW-PIPE
WELDING BENCH
H
WATER TIN
OXYGEN CYLINDER
E
F
A
B
C
D
G
GENERATOR
SCRUBBER TO REMOVE LIME
GAS HOLDER
CHEMICAL FILTER

PLATE 16A.

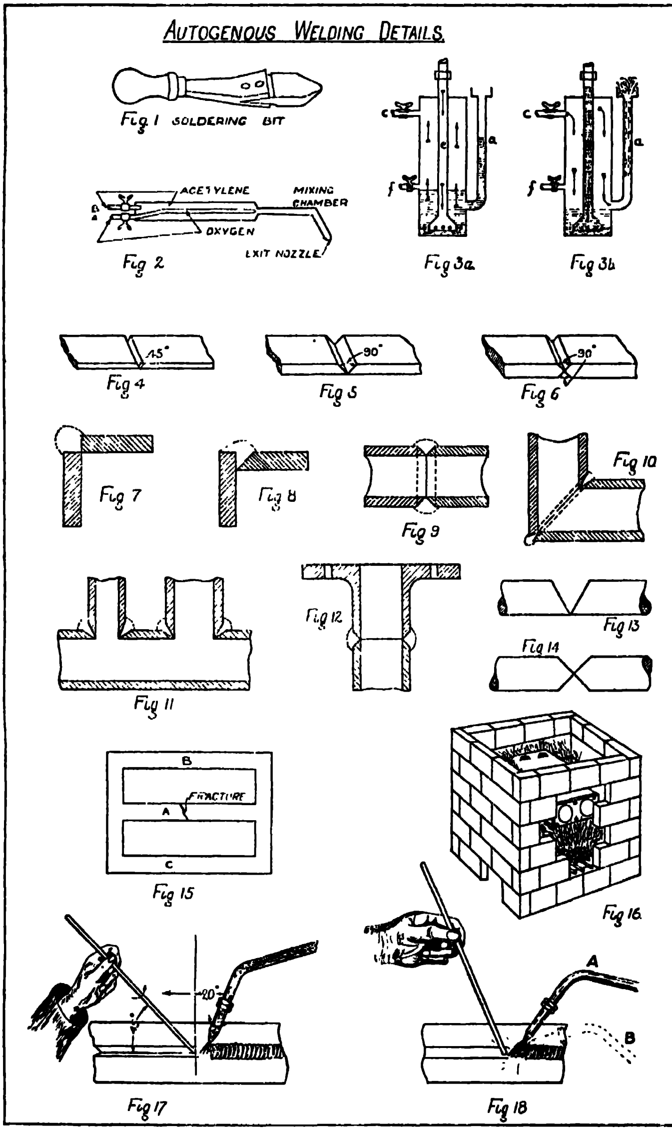

AUTOGENOUS WELDING DETAILS.
Fig 1 SOLDERING BIT
ACETYLENE
MIXING CHAMBER
OXYGEN
EXIT NOZZLE
Fig 2
Fig 3a
Fig 3b
45°
Fig 4
90°
Fig 5
90°
Fig 6
Fig 7
Fig 8
Fig 9
Fig 10
Fig 11
Fig 12
Fig 13
Fig 14
B
FRACTURE
A
C
Fig 15
Fig 16
20°
Fig 17
A
B
Fig 18

PLATE 16B.

OXY-ACETYLENE WELDING DETAILS

SECTION THROUGH WELDING REGULATOR.
Ref. 3258/64.

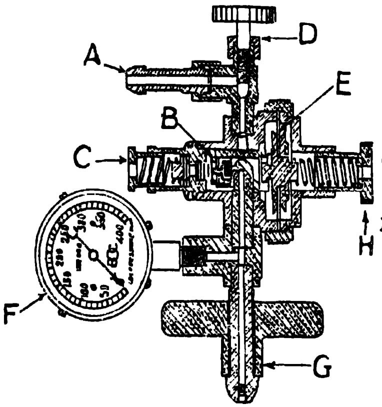


Fig. 1

A.—Outlet connection.

B.—Special valve seat — proof against ignition risk; also incorporates patent non-turn device.

C.—Safety valve—preventing accumulation of pressure inside body.

D.—Outlet valve.

E.—Special reinforced diaphragm.

F.—High - pressure gauge indicating contents of cylinder

G.—Fly-nut and nipple for inserting regulator in valve socket.

H — Pressure adjusting screw.

A cutting regulator is similar, but an outlet pressure gauge is provided between the outlet connection A and the safety valve C.

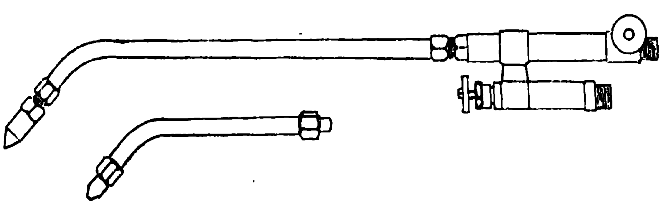


Fig 2 Model B high pressure welding blowpipe

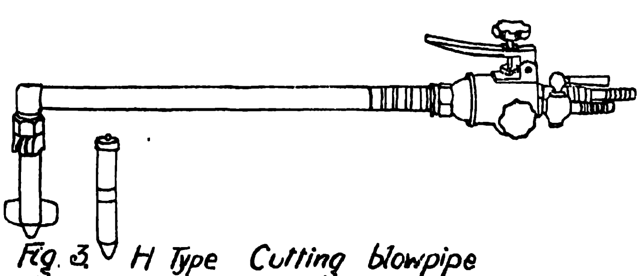


Fig. 3 H Type Cutting blowpipe

ii. *High-pressure system.*—In this system the acetylene is supplied in steel cylinders filled with a porous material, such as *Kapok.* The Kapok is saturated with acetone which has the property of dissolving large quantities of acetylene, and the gas in this form is known as *dissolved acetylene.*

The approximate weight of a cylinder containing 120 cubic feet of gas is 120 lb., the diameter $8\frac{3}{8}$ in. and the length $40\frac{1}{2}$ in. (There are 8 standard sizes of D.A. cylinders containing from $3\frac{1}{2}$ to 200 cubic feet.)

The amount of gas taken from a dissolved acetylene cylinder can be estimated from the loss of weight in use. One pound of acetylene equals about 14·5 cubic feet at normal temperature and pressure. The initial pressure in the cylinder is 225 lb./sq. in. at 60° F., and a regulator valve is therefore necessary to lower the pressure to a suitable value for control at the blow-pipe.

Fittings for *acetylene* cylinders have *left-handed threads* and are *painted red.*

The advantages of the high-pressure system are :—

(1) The plant is portable.
(2) The gas requires no purification.

On the other hand the cost of acetylene in the dissolved form is about three times as great as when generated locally, and therefore the low-pressure system is preferred for stationary work where large quantities of acetylene are consumed.

iii. *Care of cylinders and regulators.*—Both oxygen and acetylene cylinders must be handled with great care. They must be kept cool but must not be exposed to the weather. When in use they should be kept as nearly upright as possible. Repairs to regulators and cylinder valves should not be attempted locally. The cylinder valve should always be closed when the cylinder is not in use and when returned for refilling.

In no circumstances must any oil or grease be used on any of the fittings, either on the cylinder valves, regulators, tubing or blow-pipe. Oil and oxygen together form a very inflammable mixture.

Empty cylinders should be handled with the same care as full ones.

Cylinders are generally loaned, demurrage charges being paid when they are retained above a certain period.

The British Standard Specifications dealing with gas cylinders and fittings are detailed in the bibliography on page 687.

4. **Blow-pipes.**—The blow-pipe used in the low-pressure system is quite different from that used in the high-pressure

system. The former works on the *injector* principle. The oxygen rushing through the pipe A (Pl. **16A**, Fig. 2) draws in the low-pressure acetylene through the pipe B.

The British Oxygen Company's *Model B* blow-pipe for high-pressure work is illustrated in Pl. **16B**, Fig. 2. In its design is embodied a device for arresting back-firing which virtually takes the place of the hydraulic seal in the low-pressure system. The standard outfit comprises two shanks of different length and 9 interchangeable tips for welding materials up to 1 in. in thickness.

Tips, when choked, should never be reamered out with a hard instrument. Copper wire may be used.

Particulars of tips, gas consumption, &c., in the high-pressure system are given in Table **I**, which applies particularly to mild steel. It is impossible to tabulate figures for all materials and conditions but the table may be used generally for estimating purposes.

In all cases the working capacity of a tip varies somewhat according to the nature of the work and the skill of the operator. If the work is pre-heated the gas consumed for welding is reduced. It will be noted that modern regulator settings are the same for oxygen and acetylene and equal volumes of the two gases are consumed. In the low-pressure system the consumption of oxygen is some 10 to 15 per cent. greater than that of acetylene.

5. **General method of welding.**—i. *Preparing the work.* —The parts to be welded must be carefully cleaned from rust and dirt. No attempt should be made to reweld pieces which have previously been welded or brazed, without first cutting away all of the old metal. To obtain a weld of maximum strength it is usually necessary to weld through the whole section of the joint, and in order to effect this the edges of the parts to be welded are bevelled so that when the edges are placed together the included angle is about 90° for plates from $\frac{3}{16}$ to $\frac{3}{4}$ in. thick and 45° for plates from $\frac{1}{8}$ to $\frac{3}{16}$ in. (Pl. **16A**, Figs. 4 and 5).

This allows the flame to reach the bottom of the " V." When the nature of the work permits, the bevelling may, with advantage, be done from both surfaces, forming a double " V " (Pl. **16A**, Fig. 6).

In the case of cast iron and steel, pieces $\frac{1}{8}$ in. thick or less may be welded without making the " V." In brass and bronze no work less than $\frac{1}{4}$ in. thick and in aluminium nothing less than $\frac{1}{8}$ in. thick should be bevelled.

In repair work the " V " groove may sometimes be cut with a cutting blow-pipe. When welding a crack, the extremities of the crack should be drilled to prevent extension.

The preparation of angle welds is shown on Pl. **16A**, Figs. 7 and 8. That shown in the latter is the better practice, but its preparation is more expensive. Pl. **16A**, Fig. 9, shows a pipe joint, Fig. 10 a pipe elbow, Fig. 11 teeing into a pipe, Fig. 12 welding a flange, Fig. 13 rods up to $\frac{3}{8}$ in. diameter, Fig. 14 rods $\frac{3}{8}$ in. diameter and over.

Pieces of different thickness are not easily welded together, as one fuses before the other.

Contraction must be considered when preparing welds. As an example consider the repair of the fracture A in Pl. **16A**, Fig. 15. When the bar A is heated it will expand, thus closing the fracture. When the metal fuses, the two parts of A tend to close in still more to relieve the stress due to expansion. When the joint solidifies on cooling A contracts and stresses the remainder of the frame. To prevent this result it is necessary to pre-heat the whole article to as high a temperature as possible before welding is begun.

ii. *Welding rods.*—When, as is usual, the joint has been prepared for welding by bevelling, additional metal must be used to fill up the " V ". The kind of metal used for this purpose depends upon the metal being welded and it is usually supplied in the form of rods $\frac{1}{16}$ to $\frac{3}{8}$ in. in diameter.

iii. *Welding fluxes.*—In all methods of welding, prevention from oxidation is of primary importance. Not only does the presence of oxide reduce the strength of the weld but it renders the joint peculiarly liable to corrosion. As it is not always possible to incorporate in the welding rod all the elements necessary to prevent oxidation, it is generally necessary to use certain chemical compounds in the form of pastes and powders to act as deoxidizing agents.

In the present state of our knowledge of the art of welding, however, we are compelled to use proprietary brands of welding rods and fluxes if the best results are to be obtained.

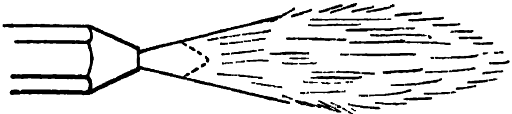
iv. *Regulating the flame.*—To commence work, turn on both oxygen and acetylene at the blow-pipe and light. The flame will probably have an excess of acetylene which should be reduced until the flame of the blowpipe has a clearly defined cone at the orifice. Final adjustment of the oxygen pressure to suit the tip in use should now be made. (*See* Table **I**.)

Unless special instructions are given to the contrary, a *neutral flame* should always be used.

Excessive acetylene will carburize the weld, and excessive oxygen will oxidize the weld.

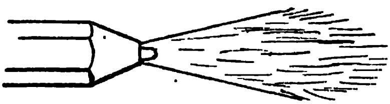
Pl. **16C**, Fig. 1, shows roughly the appearance of the flame (*a*) with an excess of acetylene, (*b*) with an excess of oxygen, and (*c*) neutral (correct). In each case the tip of the small inner white cone is the hottest part of the flame.

PLATE 16C.



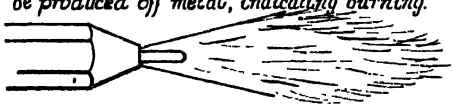
(a). EXCESS ACETYLENE (CARBONIZING FLAME).

The flame is long and brilliant, the inner cone is also long without a distinct outline. If used, the work will be hardened and discoloured.



(b). EXCESS OXYGEN (OXIDIZING FLAME).

The flame is short and pale, the inner cone is also short with violet tinge. If used, sparks will be produced off metal, indicating burning.



(c). CORRECT ADJUSTMENT (NEUTRAL FLAME).

The flame is of medium length and pale, the inner cone is sharply defined (length according to size of blowpipe).

Fig. 1

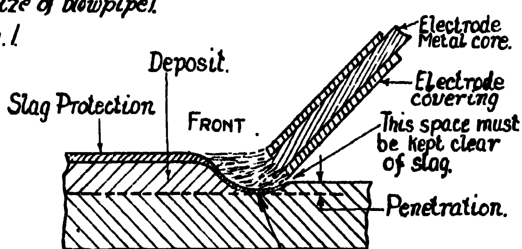


Fig. 2.

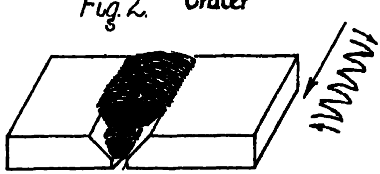


Fig. 3. Diagram of weld showing direction of point of electrode.

If the flame is not properly regulated or the tip gets momentarily obstructed by a spark, the blow-pipe may backfire and go out. When this occurs, the acetylene pipe should be shut off at once, and a few seconds allowed to elapse before reopening it and relighting the blow-pipe. On stopping work, the acetylene cock must be closed before the oxygen cock.

v. *Applying the flame.*—The blow-pipe is held in the right hand and the welding rod in the left and the weld is made by pushing the blow-pipe, not by pulling it, making a circular movement with the flame, combined with an advancing one, thus making a series of elliptical curves. (Pl. **16A**, Fig. 17.)

The angle of inclination of the blow-pipe should have particular attention. An angle of about 20° gives the best results. The welding of the rod and of the edges of the material being welded must take place simultaneously, the molten metal being puddled with the welding rod (Pl. **16A**, Fig. 18), thus breaking up the oxide film and raising all the impurities in the weld to the surface. These impurities appear as bright red spots which should be brushed away. When feeding, care must be taken not to apply the flame direct to the rod or it will be overheated.

6. **Welding cast iron.**—It is desirable, as far as possible, to fill the weld with iron which will have, when the work is finished, the same composition as the casting. If, however, a casting of grey iron is welded with a rod of the same material, the resulting weld is found to be hard, due to the conversion of grey iron into white iron. To avoid this a feeding rod of *ferro-silicon* is generally used when the part is to be machined after welding. The presence of *silicon* in cast iron tends to prevent the combination of the *carbon* with the *iron* and this favours the production of grey iron.

Manganese, if present in cast iron, tends to produce white iron by causing the free carbon to dissolve.

The work, unless small, must be pre-heated and cooled slowly on completion. A pre-heating oven is illustrated in Pl. **16A**, Fig. 16.

If the proper welding flux cannot be obtained, a flux consisting of equal parts of ordinary washing soda and baking soda (bicarbonate of soda) with a little borax added, does fairly well as a makeshift.

The flux is applied on the end of the welding rod; it should be used sparingly and not thrown on to the molten metal.

7. **Welding malleable cast iron.**—Malleable cast iron can be welded with an iron feeding rod, but the resulting weld is hard and brittle and cannot be machined. If heated for

some time near the melting point malleable cast iron reverts to its original state of white cast iron. For this reason the only satisfactory method of repairing a malleable iron casting is to use a filling material which will alloy with it far below its melting point. A manganese-bronze alloy has been largely used in the past, but a much better material known as *Sifbronze* is now available (supplied by the Suffolk Iron Foundry, Ltd.). This is an alloy of copper, zinc and tin which melts at 700° C. The process is as follows: the fracture is heated to a bright red by the blow-pipe, a little flux is sprinkled on and the welding rod applied. If the bronze remains in a globular state, the work is not hot enough, but if it spreads and adheres to the work the temperature is correct and the groove should be quickly filled. Excessive temperatures must be avoided.

It will be noted that this process is strictly "brazing," not "welding."

8. **Welding wrought iron and steel.**—In the welding of ordinary wrought iron and mild steel, a feeding rod of the same material may be used. Good results are obtained, however, by using a feeder of Swedish iron or soft iron rod as free as possible from carbon. No flux is required.

On account of the danger of damaging high carbon steels by overheating much greater care must be exercised than with low carbon steels which are not so easily damaged in this way.

Unless the work is less than ⅛-in. thick it is essential to bevel the edges, otherwise the resulting weld will not be sound owing to cold "shuts" at the bottom of the V.

Steel does not form a comparatively large melted pool as in the case of cast iron, and for this reason, and also because of its rapid solidification, it is necessary to be careful about welding the edges of the pool.

It must be borne in mind in repairing a steel article that if the qualities of the steel are due to careful heat treatment, these qualities cannot be retained after welding, even if further heat treatment be attempted. A *weld is a casting*, and re-heating to about 1,800° F. (985° C.) is necessary to break up the coarse structure of the weld, this temperature being excessive for the proper heat treatment of the original steel.

9. **Welding galvanized or tinned iron sheets.**—Before welding these the coating of zinc or tin, as the case may be, must be removed for a distance of about an inch on either side of the proposed joint. In the case of galvanized iron, if this precaution be not observed, a poor weld will result, and there is danger of poisoning from zinc fumes. In the case of tinned sheet, the tin does not volatilize but

forms, with the iron, an alloy which consists of very large crystals separated by numerous cracks. A welding rod of Swedish iron is generally used, without flux.

10. Welding copper.—Owing to the high conductivity of copper, a larger blow-pipe tip must be used than for iron and steel. Owing to the rapid loss of heat from copper it is usually economical to pre-heat the work. If the thickness of the material exceeds $\frac{3}{32}$-in. the edges should be bevelled. The feeding rod is usually of phosphor copper. A pure copper welding rod may be used but it is not so effective.

No flux is really necessary if the surfaces are properly cleaned, but a flux consisting of common salt, sodium borate and boracic acid, applied sparingly on the end of the welding rod may sometimes be found to facilitate the work. It is most essential that a neutral or slightly reducing flame should be used as copper oxidizes very readily. The weld will have the strength of cast copper; to increase the strength and ductility the joint may be hammered at a dull red heat.

11. Welding copper alloys.—The copper alloys usually met with are brasses and bronzes, the former containing zinc and the latter tin. When welding brass, some of the zinc is burnt and zinc oxide is given off in the form of poisonous white fumes. For this reason a welding rod rich in zinc is used, such as one of manganese bronze.

There is no loss due to volatile oxide in the case of bronze.

An indication that the correct welding temperature has been reached with copper alloys is given by the formation of bubbles on the surface of the molten metal, and at this point the feeding metal must be added. Plain borax may be used as a flux but it should be prepared for use by melting, cooling and then powdering. This avoids foaming up of the flux upon the weld.

12. Welding aluminium.—Aluminium is the most difficult of the common metals to weld owing to the rapid formation of oxide on the surface of the metal when heated. Under the influence of the welding flame the molten metal tends to form into globules, each surrounded by a film of oxide which is difficult to break down. Aluminium melts at 1,170° F. (630° C.) and the oxide at 5,000° F. (2,760° C.). A welding rod of pure aluminium is generally used and a special flux applied by dipping the end of the welding rod into a vessel containing the flux. Pre-heating is generally desirable, but a temperature of 900° F. (480° C.) must not be exceeded or the aluminium will become fragile and sink or be deformed under its own weight. As prolonged heating tends to make aluminium brittle the welding must be carried out as quickly as possible. When the weld is completed all traces of flux must

TABLE I.—*High Pressure Oxy-Acetylene Welding*

Approximate consumption of gases, working pressure, &c., for the various tips.

(Figures apply particularly to mild steel plate, but they may be used generally for estimating purposes.) 1 cubic foot=28·32 litres.

Number of blow-pipe tip	Blow-pipe model	Section of plate welded (inches)	Regulator pressure in lb./square inch		Corresponding indication on regulators with new type calibration	Gas consumption cubic feet per hour (acetylene)	Speed of welding minutes per foot run	Feeding rod	
			Acetylene	Oxygen				Size inches diameter	Consumption inches per foot run
Litres									
1–5	O	For lead burning or thin mild steel sheet up to $\frac{1}{16}$.	$1\frac{1}{2}$	$1\frac{1}{2}$	1	0·175	—	—	—
2–12	,,		$2\frac{1}{2}$	$2\frac{1}{2}$	1	0·425	—	—	—
3–31	,,		3	3	1	1·100	—	—	—
4–62	,,		4	4	1	2·200	—	—	—
5–125	,,		5	5	1	4·400	—	—	—
50	B	$\frac{1}{32}$	2	4	1	1·75	1·75	$\frac{1}{16}$	4
75	,,	$\frac{1}{24}$	2	4	1	2·66	2	$\frac{1}{16}$	6
100	,,	$\frac{1}{16}$	2	4	1	3·50	3	$\frac{1}{16}$	8
150	,,	$\frac{1}{12}$	2	4	1	5·25	4	$\frac{1}{16}$ or $\frac{1}{8}$	10
225	,,	$\frac{1}{8}$	$2\frac{1}{2}$	$4\frac{1}{2}$	2	7·75	7	$\frac{1}{8}$	11
350	,,	$\frac{3}{16}$	3	5	2	12·25	$7\frac{1}{2}$ to 10	$\frac{1}{8}$	16
500	,,	$\frac{1}{4}$ to $\frac{5}{16}$	4	$7\frac{1}{2}$	2	17·25	10 to 15	$\frac{1}{8}$ or $\frac{3}{16}$	21 to 27
750	,,	$\frac{5}{16}$ to $\frac{1}{2}$	5	10	3	25·00	15 to 20	$\frac{3}{16}$ or $\frac{1}{4}$	27 to 42
1,000	,,	$\frac{9}{16}$ to 1	$7\frac{1}{2}$	15	3	36·00	20 to 60	$\frac{1}{4}$	55 to 90
1,500	,,	Thicker sections.	10	20	4	54·00	—	—	—
2,000	,,		15	25	5	72·00	—	—	—
2,500	,,		20	30	6	90·00	—	—	—

be washed away with warm water and a brush. The part should then be re-heated and allowed to cool slowly.

13. **Welding aluminium alloy castings.**—The above notes on welding aluminium apply equally well to aluminium alloys, but special aluminium alloy welding rods must be used with appropriate fluxes.

14. **Welding lead.**—The autogenous welding of lead is commonly known as *lead burning.*

Although first introduced for jointing lead pipes, tanks, &c., in chemical works where acids and fumes would attack soldered joints, the process is now replacing ordinary plumbing and soldering in many other operations with a great saving of time and labour.

The seams in sheet lead burning are of two kinds, *butt* and *lap*, and the two edges are not usually bevelled. The lap joint should be used in both horizontal and vertical seams on a vertical surface. The only preparation necessary is the cleaning or shaving of the edges of the metal near the joint. A plain lead feeding rod is used and the flame must be absolutely neutral. No flux is required.

The ordinary standard oxygen and acetylene cylinders may be used but a special lead burning outfit must be employed. This includes special regulating valves for both oxygen and acetylene cylinders, and a special blow-pipe with a number of interchangeable tips (generally 5). Nos. 1 and 2 tips are used with 2 and 3 lb. lead and No. 5 tip with 20 to 30 lb. lead. The lead burning outfit can be used for thin sections of other metals up to $\frac{1}{16}$ in. in thickness.

Table I gives the approximate consumption of gas with the various tips. It will be noticed that the gas consumption is relatively small compared with that required for welding the harder metals.

33. *Electric welding*

1. There are two main processes of electric welding, *viz.*: (1) *resistance welding*, in which the welding heat is generated by the contact resistance at the junction to the passage of an electric current, and (2) *arc welding.*

Resistance welding is possible with almost any metal, but arc welding is really only suitable for ferrous metals and alloys.

2. **Resistance welding** includes *spot, butt* and *seam* welding. The process is really similar in principle to forge welding, the temperature of the work being raised to a suitable value and the welding effected by pressure or percussion. Resistance welding is largely used in factories for repetition work which can be carried out in automatic machines by semi-skilled labour. A.C. is invariably used owing to the

facility with which the large currents required can be obtained conveniently and economically from static transformers connected to the ordinary public electricity supply.

3. In **arc welding**, as its name implies, the work forms one of the electrodes of an electric arc. When this system was first introduced the other electrode used was a carbon rod, and additional metal was added by a feeder rod as in the oxy-acetylene system. The work was originally made negative and the carbon rod positive, but subsequently the rod was made negative to minimize the amount of carbon carried into the weld.

Carbon arc welding is still sometimes used for certain purposes where no particular strength is required, such as in filling blow holes in castings, but for general purposes it cannot now compete with metal arc welding, in which the carbon rod is replaced by a metal rod which also acts as the feeding rod.

The great drawback to the carbon arc is that it produces a very porous and brittle weld owing to the combination of the molten metal with volatilized carbon and with oxygen from the atmosphere.

4. **Metallic arc welding.**—i. *Polarity of the work.*—Although satisfactory welding can be done with A.C., distinctly better results are obtained with D.C.

The mechanism of the transfer of metal across the arc is not yet fully understood, but the difference of temperature between the electrode and the more massive work appears to be the chief condition necessary for the transfer.

When welding with D.C. and *bare* or lightly covered electrodes it is usual to connect the *positive* (the hotter) pole to the *work*, to assist the operator in fusing through the mill scale or other impurities on the surface of the parent plate, which have a relatively high melting point. On the other hand with *flux covered electrodes* the acid slag formed cleans the parent plate chemically, and it is therefore possible to make the *electrode positive*, thus increasing the rate of deposition and consequently the speed of welding.

ii. *Electricity supply.*—Mainly in order to minimize oxidation the welding arc is kept as short as possible ($\frac{1}{8}$ to $\frac{1}{4}$ in.). A voltage of the order 17 to 25 volts is sufficient to *maintain* this short arc, but to *strike* it a much higher voltage is required.

Considering first a D.C. supply, the arc voltage is much lower than that of ordinary electricity supply systems, and it is therefore necessary to use a large series resistance or a motor generator. The waste of energy is considerable in either case. Further, as the full supply voltage appears

between the electrode and the work when the arc is broken, it is unwise to practise welding on supply voltages higher than 110 volts through a series resistance.

Not only does a high voltage increase the liability to draw a long flaming arc which will overheat and burn holes in the work, but it increases the danger from electric shock.

If the local supply is A.C. it is preferable to use a double wound static transformer or a motor generator. It is permissible to use a series resistance on voltages up to 110 volts A.C., but it must be pointed out that A.C. is definitely more dangerous than D.C. of the same maximum voltage, and the former must never be used inside boilers or where the operator has to work on lofty staging.

In situations involving special risk from electric shock, D.C. at a voltage not exceeding 50–60 volts should be used.

The use of A.C. for welding is not recommended for service purposes, particularly in exposed situations. Apart from the increased danger from shock, A.C. welding is more difficult to learn, and the results are not so uniformly reliable as those obtained with D.C. welding.

Moreover, *flux-covered electrodes must* be used with A.C. With D.C., plain electrodes may sometimes be used in emergencies with satisfactory results.

The best work is done with a special D.C. welding generator with a drooping voltage characteristic, *i.e.* a voltage which falls as the current rises, giving a voltage of about 60 on open circuit and 15–30 volts when the welding current is flowing. An inductance is generally inserted in series with the arc to increase the voltage to 100 momentarily if the arc goes out. This is necessary with flux-covered electrodes to pierce the slag layer.

The Home Office "Memorandum on Arc Welding" (Form 329) has been drawn up for the guidance of those concerned with the provision and observance of precautionary measures. This memorandum should be carefully studied.

iii. *Electrodes.—Bare mild steel electrodes* can be used in emergencies, preferably in conjunction with a flux such as borax or black oxide of manganese, but the welds obtained are not so uniformly satisfactory as those effected with paste or flux-covered electrodes.

Paste-covered electrodes are largely used, the object of the paste coating being to minimize oxidation, firstly by protecting the electrode itself, and secondly, by forming a gaseous envelope around the molten metal to keep it from contact with the atmosphere. Many kinds of solutions and pastes are in use to make up coating compounds, one of the simplest (used for mild steel) being a mixture of lime 65 per cent. and silica 35 per cent.

Flux-covered electrodes have a thick covering usually consisting of an asbestos base impregnated with deoxidizing substances. The best known type of flux-covered electrode is that used in what is called the *quasi-arc system* which will be briefly described as a typically good system.

iv. *Quasi-arc system.*—The electrodes used in this system are covered with a mineral flux having singular chemical properties, whereby a weld of the highest mechanical strength and purity is obtained. The flux is in the form of a suitably treated asbestos yarn, spirally wound on the core and therefore not easily detachable as is the case with paste flux. The electrodes are supplied in standard lengths of 18 in. and with cores of various diameters according to the size and nature of the work. The composition of the electrode is arranged to suit the particular material being welded, and the different kinds are distinguished by colours. *Mild steel electrodes* (coloured blue) are used for the general welding of wrought iron and mild steel and *carbon steel electrodes* (red) for reinforcing worn parts of machinery, teeth of steel gear wheels, &c. Special electrodes (yellow) are supplied for the repair of iron castings. The particular advantages claimed for these electrodes are :—

(*a*) Low melting temperature, which reduces expansion and contraction of the casting to a minimum.

(*b*) Metal deposited is soft and ductile and able to yield to stresses introduced by contraction.

(*c*) Metal deposited is machinable.

(*d*) Special flux prevents formation of white iron.

Practically any ferrous alloy can be welded electrically providing suitable welding electrodes are employed.

The flux coating of the quasi-arc electrodes melts at a lower temperature than the iron and when hot becomes a secondary conductor of electricity. The flow of molten slag (which appears *bright red*) forms a sheath protecting the arc and the molten metal (which appears dark red) from atmospheric oxidation and also fluxes away dirt and oxide from the weld. A small wire of aluminium, which is incorporated in the electrode assists in preventing oxidation.

In addition, the molten slag sheath provides a stabilizing effect on the arc and enables it to be kept burning at a lower current than is possible with bare or lightly covered electrodes. It also tends to localize the heat.

During welding, the tip of the electrode is kept just below the surface of the molten slag and the appearance of the screened arc gives the name *quasi-arc* to the process.

v. *General method of welding.*—Owing to the cleansing and

fluxing action of the asbestos sheathing it is unnecessary to clean the work before welding.

The size of the electrode to be used will depend upon the amount of metal to be deposited, but in the case of work *liable to be distorted* overheating by the use of too large an electrode must be avoided.

If the work to be welded is of considerable thickness the joint must be built up by successive runs of metal.

Plate **17** gives electrode sizes, current and other particulars for butt welding. Lap welds are carried out more quickly than butt welds and with a smaller electrode consumption.

The *electrode*, held in a suitable holder, is connected to the *positive* pole of the supply and the work to the negative. It cannot be too strongly impressed upon the operator that he must use a proper non-conducting screen fitted with correctly coloured glasses, otherwise his eyes will, very soon, be seriously injured.

Electrical contact is first made by touching the work with the end of the electrode, held vertically, thus allowing the current to flow and an arc to form (when working out of doors the arc should be protected from the wind or the work will be extremely difficult). Directly the arc is struck, the electrode, with the tip just below the surface of molten slag, is brought towards the operator in the direction in which the weld is to be made, and then kept at an angle of 45° or so with the work. (*See* Pl. **16C**, Fig. 2.) This is in order to keep the molten metal and the slag in *front* of the electrode.

The electrode should be gripped with just sufficient force to hold it, but the wrist should be free. A light touch and a side to side movement with the point of the electrode gives the best results in distributing the heat and depositing metal equally on both sides of the seam. (*See* Pl. **16C**, Fig. 3.)

Sufficient current should be used so that the weld metal runs freely with no tendency to pile up. If too much current is used the metal will run fiercely and be uncontrollable.

When more than one layer of weld metal is deposited the slag from the previous layer must be chipped off before the next is applied. A special chipping hammer, clear glass screen and wire brush are supplied for this purpose.

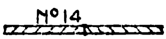
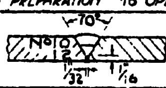
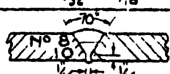
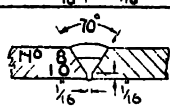
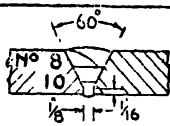
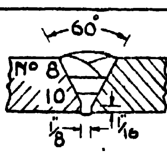
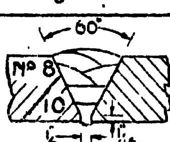
For further details the maker's instruction handbook must be referred to.

5. Electric welding of non-ferrous metals is seldom attempted. *Copper* and *copper alloys* can be welded, using a tinned copper flux-covered electrode, but it is a delicate operation owing to the high temperature of the arc and the consequent danger of piercing the work. The difference of temperature between the welding and fusing points is small and it is difficult to strike a mean between fluid and sluggish metal.

PLATE 17.

APPROXIMATE CONSUMPTION OF QUASI-ARC ELECTRODES & TIME OCCUPIED PER FOOT OF WELD.

BUTT WELDS.

TYPE OF WELD	ELECTRODES				TIME OCCUPIED	
	NUMBER OF RUNS	SIZE OF ELECTRODE	CURRENT	FEET OF ELECTRODE PER FOOT OF WELD	NETT WELDING TIME	PRACTICAL TIME INCLUDING WELDING CLEANING & FINISHING
		SWG	AMPERES		MINUTES	MINUTES
1/16" PLATES  N° 14 NO PREPARATION CLOSE JOINT	1	N° 14	35	1 FT	1½	1¾
1/8" PLATES  N° 12 NO PREPARATION CLOSE JOINT	1 OR	N° 12	65	1½ FT	2	2½
	1	N° 10	80	1¼ FT	2	2½
3/16" PLATES  N° 10 NO PREPARATION 1/16" OPEN	1	N° 10	70	2¼ FT	3½	4¼
1/4" PLATES  70° N° 10 12 1/32" 1/16"	1	N° 12	50	2 FT	2¾	7
	1 TOTAL 2 RUNS	N° 10	85	2 FT	3	
5/16" PLATES  70° N° 8 10 1/16" 1/16"	1	N° 10	85	2 FT	3	8½
	1 TOTAL 2 RUNS	N° 8	105	2½ FT	4	
3/8" PLATES  70° N° 8 10 1/16" 1/16"	1	N° 10	85	2½ FT	3¾	11½
	1 TOTAL 2 RUNS	N° 8	105	3½ FT	5¾	
1/2" PLATES  60° N° 8 10 1/8" 1/16"	1	N° 10	85	3 FT	4½	19¼
	3 TOTAL 4 RUNS	N° 8	105	7 FT	11½	
5/8" PLATES  60° N° 8 10 1/8" 1/16"	1	N° 10	85	3¾ FT	5¾	31
	4 TOTAL 5 RUNS	N° 8	105	12 FT	20	
3/4" PLATES  60° N° 8 10 1/8" 1/16"	1	N° 10	85	4½ FT	6¾	46
	5 TOTAL 6 RUNS	N° 8	105	19 FT	31½	

6. **Aluminium** definitely cannot be welded with the electric arc. The heat is so great that the metal is vaporized and destroyed before a joint can be made.

34. *Metal cutting by gas and electricity*

1. **Metal cutting by gas.**—If a jet of oxygen be directed upon wrought iron or mild steel, previously well cleaned and heated to redness, the metal will ignite and, acting as its own fuel, it will burn away rapidly, forming iron oxide.

Theoretically, this burning should continue so long as sufficient oxygen is supplied, without additional heat from outside, but the oxide, unless removed, will stop the action. Fortunately, the oxide melts at a lower temperature than the wrought iron or mild steel, and being in liquid form when the metal is molten it is blown away by the oxygen jet provided that sufficient heat is applied to keep it fluid. The necessary heat is provided by an oxy-acetylene flame.

The process of cutting by gas is only really economical when the oxide has a melting point lower than that of the metal. High carbon steels whose melting points are appreciably lower than that of mild steel and in the neighbourhood of the melting point of the oxide do not cut very well, and *cast iron can only be cut with great difficulty* and with a relatively large gas consumption. Most other metals, including *copper, brass, bronze and aluminium,* do not burn in oxygen in the manner described above and therefore *cannot be cut by gas.*

A special blow-pipe is used for cutting, with two orifices in the nozzle—one in the centre for the oxygen igniting jet and the other, an annular orifice, for the oxy-acetylene heating flame.

Pl. **16B,** Fig. 3, shows a cutting blow-pipe, Model H, as supplied by the British Oxygen Co., for cutting mild steel up to 7 in. thick and cast iron up to $1\frac{1}{2}$ in.

As far as the heating flame is concerned, the blow-pipe is of the injector type, and it can be used on both low-pressure and high-pressure systems. The central oxygen jet is separately controlled.

To make a cut.—The surface of the metal should first be well cleaned. Then the heating flame is applied, and when the metal is nearing fusion the central oxygen jet is turned on. As soon as ignition of the metal begins, the process can be made progressive along the line it is desired to cut. Excessive speed or irregular advancement will cause a stoppage of the cutting, due to the oxygen meeting metal not hot enough to burn. The oxygen jet should be turned off when this happens as it only tends to make the metal cooler. To restart, it will be necessary to go back a little way along the line of the cut and re-heat before turning on the oxygen jet again.

For metal cutting operations the working pressures and the rate of consumption of oxygen are considerably greater than for welding operations—therefore, although the acetylene regulator as used for welding is quite suitable for the acetylene supply required for cutting, it is necessary to replace the oxygen regulator and to use one of larger capacity and capable of maintaining higher working pressures than are required for welding. Such oxygen regulators are always provided with two gauges, one for indicating the pressure of gas in the cylinder and the other the working pressure.

Table J gives the approximate gas consumption, speed of cutting, &c., for mild steel up to 2 in. and cast iron up to 3 in. in thickness.

TABLE J.—*Oxy-acetylene cutting*

APPROXIMATE CONSUMPTION OF GASES, WORKING PRESSURES, &C.

Material and thickness cut	Nozzle		Oxygen pressure	Speed of cutting	Gas consumption per foot run	
	Size	Distance from work			Oxygen	Acetylene
ins.	ins.	ins.	lb./sq. in.	minutes per ft. run	cu. ft.	cu. ft.
Mild steel						
$\frac{1}{4}$	$\frac{1}{32}$	$\frac{3}{16}$	24	1	0·75	0·2
$\frac{1}{2}$	$\frac{1}{32}$	$\frac{3}{16}$	28	1	1·0	0·3
1	$\frac{1}{16}$	$\frac{3}{16}$	32	$1\frac{1}{2}$	2·2	0·5
2	$\frac{1}{16}$	$\frac{7}{32}$	45	2	5·0	1·0
Cast iron						
Up to $1\frac{1}{2}$	$\frac{3}{64}$	$\frac{3}{8}$	110	5	30·0	10·0
$1\frac{1}{2}$ to 3	$\frac{1}{16}$	$\frac{1}{2}$	120	7	50·0	15·0

2. **Metal cutting by the electric arc.**—For cutting purposes it is preferable to use the carbon arc. A voltage of 35–40 volts is required and for mild steel a current of 400 amps. up to $\frac{3}{4}$-in. thick and 600 amps. from 1 in. to 4 in. The arc length should be as great as can be maintained and may vary from $\frac{1}{2}$ in. to 2 in. according to the kind of work being done. The time required to cut one foot run is approximately 1·25 minutes for $\frac{1}{2}$ in. and 3·75 minutes for 1 in. iron or steel. Flux-covered metal electrodes can be used for cutting with a current strength about half that required when using carbon electrodes, but the electrode consumption is very high.

Cutting by the electric arc is quite a different process from that of cutting by gas, and in the case of mild steel it is somewhat more expensive. The great success of gas cutting is largely due to the blowing away of the molten metal and oxide by the oxygen jet. In arc cutting no such action is present,

hence gravity must be relied upon to clear the molten metal from the cut, which should therefore, where possible, be started from the lower side of the work in order that the molten metal can fall freely away.

The great advantage of *arc cutting* is that it can be *applied* equally well *to almost any metal.* As stated above, cast iron is difficult to cut by gas, but it is quite easy to cut electrically.

The cut obtained by the electric arc is not so neat as that possible with gas owing to the tendency of the arc to oscillate from side to side. There are many cases, however, where the roughness of cut is immaterial, particularly in demolition work, and the cutting up of scrap iron castings is done more quickly and cheaply by electricity than by gas.

When cutting with the electric arc, special attention must be paid to protection for eyes, skin and clothes.

35. *Gas and electric arc systems of welding and cutting compared*

The great advantage of *arc welding* over gas welding is that *the heat is more localized.* The temperature of the work is higher with arc welding but *the quantity of heat required is less,* and as it is spread over a more restricted area there is not the same liability to distortion of the work. The need for pre-heating is less and the speed of welding greater.

For the repair of boilers *in situ,* arc welding is pre-eminent, and it is becoming standard practice in building construction.

There are, of course, many welding operations which can be done equally well with electricity as with gas, and in large workshops it is common practice to use both systems, gas on the smaller sections (say) up to ¼ in., and electric on the larger.

As stated before, the arc is not suitable for welding non-ferrous metals. On the other hand, the arc can be used for *cutting* any metal, and it is preferable to gas for cutting high carbon steels and cast iron.

Gas is undoubtedly much superior to the arc for *cutting* wrought iron and mild steel, and is more often used for this purpose than the electric arc.

For general *service in the field* there is no doubt that, in the present state of our knowledge, *the high pressure oxy-acetylene outfit is most suitable* on account of its portability and its greater general utility. But the possibilities of arc welding and cutting should not be lost sight of in emergencies if a supply of electricity is available, as the very simple equipment which will be required can frequently be extemporized locally.

For Bibliography, see page 687.

CHAPTER VIII

FITTERS' SHOP WORK

36. *Work and tools*

1. **Definition.**—Strictly speaking, *fitting* is the operation of reducing accurately by manual work a rough casting, forging, or other piece of metal to the required shape and dimensions by the removal of the surplus metal, but the term covers various other operations such as assembling parts and adjustments to engines and machinery.

2. **Operations.**—The operations included in fitters' work are :—

i. Chipping.
ii. Filing.
iii. Scraping, lapping, and polishing.
iv. Drilling, reaming, tapping, and screwing.

3. **Holding work.**—*The vice.*—Work is nearly always held for hand-fitting in a parallel-jawed vice, as shown on Pl. **18**, Fig. 14. A quick release for the screw is sometimes provided, which is convenient but not essential. The jaws should be faced with hard milled-steel strip to prevent slipping, but a pair of *clamps*, either of copper or lead, should always be available for use in order not to mark finished work.

4. **Personal tools.**—

i. *Hammer and chisels.*—Fitters generally use a ball pane hammer, Pl. **18**, Fig. 1, either 16 or 24 oz. in weight, with a straight shaft about 12 inches long. The face should be slightly convex and hardened.

Cold chisels are of five main shapes, as shown on Pl. **18**, Fig. 2, and these are sufficient for all ordinary work. They are made by drawing-down from octagon bar of medium tool steel; then they are rough ground, hardened, and their edges are tempered to a brown or purple colour to suit nature of work.

The apex angle of the edge is generally 70° for cutting cast steel or cast iron, 60° for wrought iron or mild steel, and 50° for brass and other soft metals. For fine work, rather sharper angles may be used. Cutting edges should be slightly convex.

In flat, side, and cross-cut chisels, the edge should be slightly broader than the body, so that the chisel will not jam; but the edge must not be too much splayed out, or the corners will break off.

ii. *Files.*—Files are made from very hard steel in a large range of sizes and varieties. To identify a file completely, it is necessary to specify :—

(*a*) The length (usually from 3 inches to 18 inches).

(*b*) The cut ; this may be *single-cut, double-cut,* the usual cut for fitters' work, or *rasp,* used chiefly for wood and other soft materials. Any of these three types of cut may be found in different degrees of fineness, described as *coarse, bastard, second cut, smooth,* and and *dead-smooth.* (*See* Pl. **18,** Fig. 10.)

(*c*) The type of file.—Files may be of various sections, as shown in Pl. **18,** and are usually tapered ; *hand files* are flat, parallel sided, and tapered in thickness ; *flat and square files* are tapered in width and thickness ; *warding files* are tapered in width only ; while *mill files* are not tapered. A *gulleting file* is round and parallel ; a *round file* is round and tapered. Tapered files are slightly *bellied.*

Files may have an edge uncut for filing close up to a finished surface without damaging it. These are known as *safe-edge files.*

A round edge is sometimes provided in mill files for finishing slots, and in saw files for gulleting teeth.

A worn file produces a smoother surface than a new one on steel, but will not cut brass or cast iron, for which new files should be used.

Files for use with mild steel are made with the cuts at a more acute angle than those for use with cast iron.

iii. *Hacksaw.*—A hacksaw may be regarded as a parting file, with all safe edges except one. Being thin, it needs a frame to keep it straight, and needs careful handling to avoid breakage.

iv. *Scrapers.*—Pl. **18,** Fig. 11 shows some types of scrapers, mostly made from old files. The edges should be dead hard, or only very slightly tempered, and the apex angle nearly 90°.

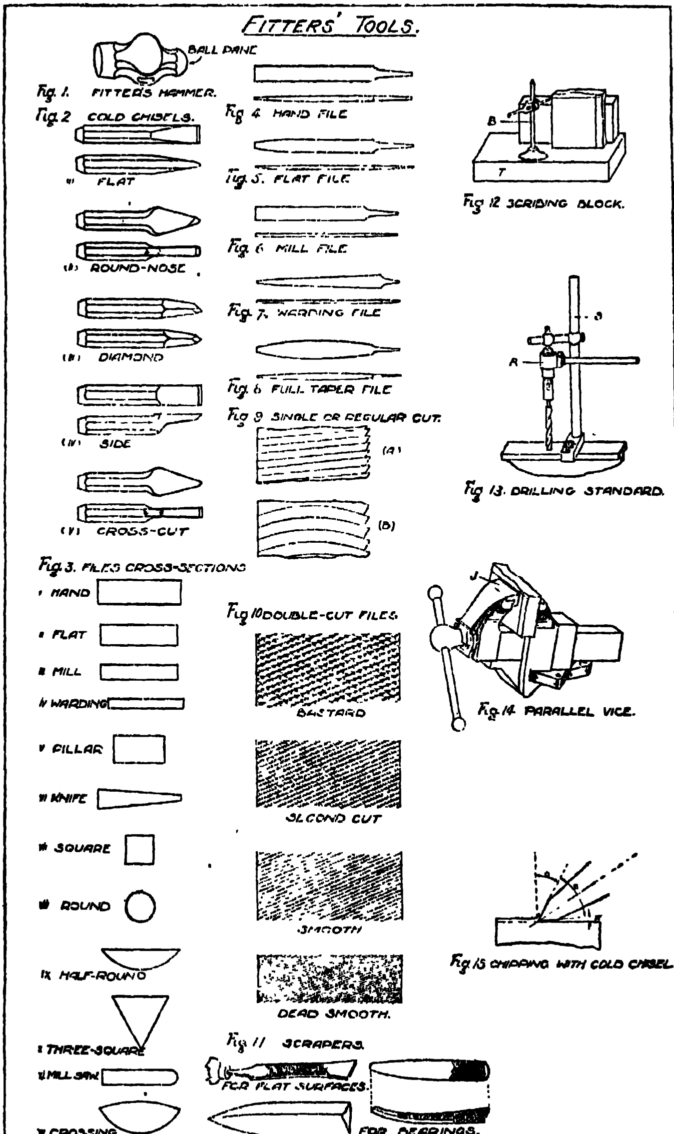
v. *Punches.*—Centre punches should have an apex angle of 90° for heavy work and 60° or less for fine work only.

A list of tools required by a fitter for personal use only is given in Appendix VII.

5. **Shop tools.**—In addition to personal tools a fitter may need other tools occasionally. Such tools should be kept in a shop tool-store, to be drawn only when required and returned when finished with.

i. *Scribing blocks.*—A scribing block, B on Pl. **18,** Fig. 12, is used to make horizontal lines upon a casting or forging, such as keyways, centres of shafts, &c.

PLATE 18.


FITTERS' TOOLS.
BALL PANE
Fig. 1. FITTERS HAMMER.
Fig. 2 COLD CHISELS.
FLAT
ROUND-NOSE
DIAMOND
SIDE
CROSS-CUT
Fig. 3. FILES CROSS-SECTIONS
HAND
FLAT
MILL
WARDING
PILLAR
KNIFE
SQUARE
ROUND
HALF-ROUND
THREE-SQUARE
MILL SAW
CROSSING
Fig 4 HAND FILE
Fig 5. FLAT FILE
Fig 6 MILL FILE
Fig 7. WARDING FILE
Fig 8 FULL TAPER FILE
Fig 9 SINGLE OR REGULAR CUT.
(A)
(B)
Fig 10 DOUBLE-CUT FILES.
BASTARD
SECOND CUT
SMOOTH
DEAD SMOOTH.
Fig 11 SCRAPERS.
FOR FLAT SURFACES.
FOR BEARINGS.
Fig 12 SCRIBING BLOCK.
Fig 13. DRILLING STANDARD.
Fig 14 PARALLEL VICE.
Fig 15 CHIPPING WITH COLD CHISEL

ii. *Marking-out table.*—The casting, &c. is placed upon a marking-out table, T on Pl. **18,** Fig. 12, the top of which is usually of cast iron, machined truly flat and set up horizontal. The scribing block can then be slid along the table, and its point will trace a horizontal line.

iii. *Drills.*—Drilling is usually carried out with a drilling machine, but a fitter may occasionally be obliged to drill by hand.

iv. *Drilling standard and brace.*—Pl. **18,** Fig. 13 shows a drilling standard, S, for hand-drilling by means of a ratchet brace, R.

v. *Reamers and taps.*—Reamers are trueing drills for finishing holes accurately to size which have first been drilled slightly small, Pl. **19,** Fig. 13. An ordinary reamer cuts near its point only, the parallel shank being merely a guide for the point.

Taps are reamers with threads on them to form a corresponding thread in the hole.

Taps are provided full and medium taper, and also plug for finishing blind holes, Pl. **19,** Fig. 14.

37. *Bench work*

1. **Hand-fitting.**—When a fitter receives a casting or forging, and a drawing of the finished article, he must first decide how much material will have to be removed from each face. He should then choose one face to use as a base. If the shape of the casting permits, a line should be scribed all round to show the amount of metal to be removed; to do this the casting is treated with quick-drying white paint and a scriber, or sharply-pointed piece of steel wire, is drawn round, guided by a straight-edge or steel rule. Brass wire gives a very distinct mark on iron and steel.

The work is then so mounted in a vice that the scribed line is horizontal and a little above the top of the jaws of the vice. A few small centre-punch marks should be made along the line, as it may become difficult to see if the paint gets rubbed off, Pl. **18,** Fig. 15.

2. **Chipping a surface.**—If the surface is very hard, or coated with fused sand, or in any case if a large amount of metal is to be removed, a hammer and cold chisel should be first used to bring down the metal to $\frac{1}{10}$ in. or less above the finished size. A good fitter can chip a narrow surface to within 0·02 inch of accuracy.

The hammer should be used with a free swing vertically upwards over the right shoulder, and in delivering a blow the eye should be directed on the work, *not* on the chisel-head.

The chisel should be held loosely so that the point or edge is in contact with the surface of the work, and one of the ground faces nearly, but not quite, parallel with the surface, Pl. **18**, Fig. 15, and this provides a relieving angle, A, of about 5°, or a little more as may be found necessary, to make the edge bite. The other ground surface will then form a wedge with a cutting angle, B, equal to the apex angle of the tool, and the angle C is the angle of rake, which ensures the separation of the chip, by breaking it off or curling it up, according to the brittleness or ductility of the material which is being chipped.

Obviously, the more acute the apex angle B, the more freely will the chisel cut, but if it is too acute, the edge will be weak and break easily.

On mild steel or cast steel a small amount of thin oil may greatly assist the work ; it is easily supplied by occasionally pressing the edge of the chisel into a pad of oily cotton rag kept upon the bench for the purpose.

A chisel should be chosen of a shape suitable for the particular work in hand.

The chisels shown on Pl. **18**, Fig. 2 are intended for the following types of work :—

i. Flat, for ordinary flat surfaces and edges.
ii. Round nose, for round grooves and curved hollow work.
iii. Diamond, for V grooves and cutting into sharp corners.
iv. Side, for flat surfaces difficult of access, such as the sides of keyways.
v. Cross-cut, or cape, chisel, for rectangular grooves, such as keyways.

Large surfaces are difficult to chip flat. The work is facilitated if a number of grooves are first chipped to the required depth by a cross-cut chisel, and the metal between the grooves then removed by a flat chisel.

3. **Filing a surface.**—The least metal should be left for filing that will ensure the production of a fair surface, since the removal of metal with a file is a slow and laborious process.

The file should be regarded more as an instrument of precision for finishing than as a tool for removing metal.

The mounting of the work in the vice is a matter of great importance. It must be firmly held, with the surface to be filed truly horizontal.

The file should be held preferably with the first finger of the right hand laid along the side, the other fingers clasping the handle in the palm, and the forearm nearly horizontal and close to the body. The left hand should be used to apply pressure at the far end of the blade, using the palm with a large file, and a finger and the thumb with a small one.

The file must remain horizontal throughout a stroke, gradually shifting the pressure from the left hand to the right. A stroke should be produced by a slight movement of the right arm from the shoulder and by a sway of the body towards the work, the force of each stroke being about equal. Strokes should be long, slow, and steady, the pressure being applied only on the forward motion.

At first a fairly rough cut file should be used, and then the work, when nearly down to size, can be given a good finish by using a smoother one.

The surface, when finished, should be perfectly horizontal and dead flat. The flatness can be tested during the progress of the work by laying a straight-edge upon the surface. There should be no *rock* at all; little light should be visible between the straight-edge and the work, and then only as a uniform streak all along the edge. Such a surface can only be obtained by keeping the file level throughout every stroke.

Some materials quickly choke the teeth of files. To clear them, a wire brush, known as a file card, may be used. When filing wrought iron and mild steel, clogging can be much reduced by filling the clearances between the teeth with chalk, but this reduces the speed of cutting. Chalk should never be used with cast iron.

4. **Using a taper file.**—It is much easier to produce a flat surface with a taper file than with a dead flat one. There is always a tendency to rock the file slightly, and so produce a convex surface. The curved surface of a well-tapered file tends to make a concave surface and counteracts any slight rocking.

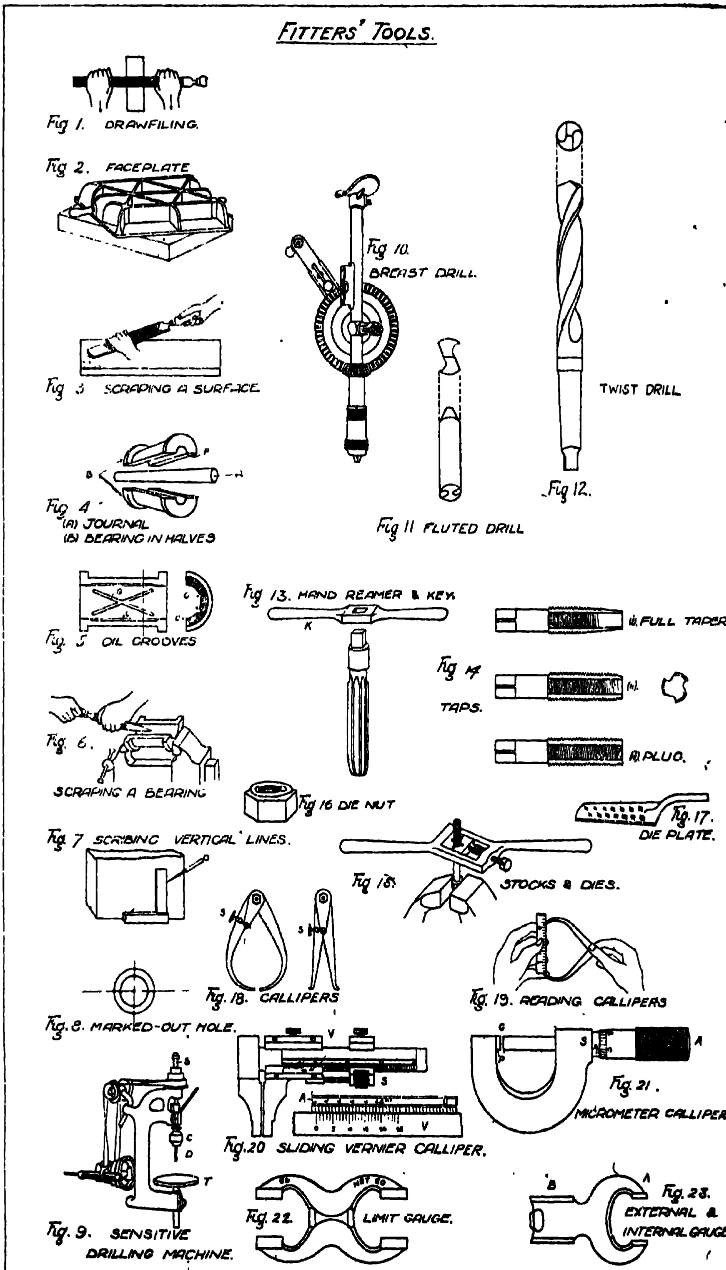
For correcting errors, the *belly* of a taper file makes it possible to file down high places on the work without affecting the rest of the surface.

Many files warp during the hardening process, which is done after they are cut. One face may, therefore, be hollow and the other bellied. The hollow side is useless for flat filing, but may be utilized for work of a round or irregular outline. Most of the files shown in the Vocabulary of Stores are *taper*. *Mill* files are parallel.

5. **Safe edges.**—Safe-edged files have one or more edges left uncut, so that they may be used close up to a finished shoulder without damaging it. The safe edge of a new file should be carefully ground down and the corners slightly rounded, otherwise the teeth would overhang the corners and score the shoulder of the work.

6. **Draw filing.**—File marks may be removed from the surface of the work by draw filing, Pl. **19**, Fig. 1, a fine-cut file being drawn sideways across the surface. A little metal is

PLATE 19.


FITTERS' TOOLS.
Fig 1. DRAWFILING.
Fig 2. FACEPLATE
Fig 3 SCRAPING A SURFACE
Fig 4 (A) JOURNAL (B) BEARING IN HALVES
Fig 5 OIL GROOVES
Fig 6. SCRAPING A BEARING
Fig 7 SCRIBING VERTICAL LINES.
Fig. 8. MARKED-OUT HOLE.
Fig. 9. SENSITIVE DRILLING MACHINE.
Fig 10. BREAST DRILL.
Fig 11 FLUTED DRILL
Fig 12. TWIST DRILL
Fig 13. HAND REAMER & KEY.
Fig 14 TAPS.
FULL TAPER
PLUG.
Fig 16 DIE NUT
Fig. 17. DIE PLATE.
Fig 15. STOCKS & DIES.
Fig. 18. CALLIPERS
Fig. 19. READING CALLIPERS
Fig. 20 SLIDING VERNIER CALLIPER.
Fig. 21. MICROMETER CALLIPER
Fig. 22. LIMIT GAUGE.
Fig. 23. EXTERNAL & INTERNAL GAUGE

removed, only very fine file marks are left, and, if carefully done, a highly finished surface is obtained.

7. Emery finishing.—A polished surface can be produced after draw filing by rubbing with a piece of fine emery cloth, or with leather rubbed with emery oil-paste, wrapped round the file. *But a good fitter disdains the use of emery.*

8. Scraping a surface.—When a flat surface is required to be more accurate than can ordinarily be produced by filing alone, it should be filed as flat as possible, draw-filed, and then scraped to fit a face-plate.

Face-plates are usually made of cast iron, Pl. **19**, Fig. 2, ribbed or otherwise made stiff enough to bear considerable pressure without warping, and very carefully finished to a dead-flat surface.

The face-plate should be rubbed over with the palm of the hand, slightly moistened with a thin paste of oil and red lead, or preferably venetian red, if available. Only the smallest amount of paste that will colour the plate should be used.

The face-plate is then applied to the surface of the work, or the work to the plate if more convenient, and moved about a little while in contact. On separating the surfaces, high spots on the work will be coloured by the paste from the plate. These high spots should be carefully scraped down by short strokes with the scraper, as shown on Pl. **19**, Fig. 3, the coloured metal only being removed. All the strokes should be in the same direction.

The face-plate should then be applied again, and the high spots will now be smaller but more numerous than before. They should be similarly scraped down, the strokes being made *in another direction.*

The operation should be repeated until the coloured spots appear as highly polished metal, and are very small and evenly distributed over the whole surface.

Curved surfaces can be similarly scraped to fit any standard surface of opposite curvature. If the surfaces are such that no relative movement can be made, the colouring paste can be made to transfer itself from the master surface to the high spots on the work, by forcing the surfaces together by a blow from a wooden mallet.

9. Scraping a bearing.—A special case of scraping curved surfaces is the scraping-in of a bearing. Some knowledge of the principles of lubrication is essential if success is to be obtained (*see* Chap. XXXIII).

New bearings on productive work should require very little scraping-in if they are machined according to the B.S.I. standards of clearance fits (*see* B.S.I. Spec. 164). Take, for example, a $1\frac{1}{2}$-in. shaft and bearings. A good clearance fit

would be obtained from the following limits U. Q. The U hole for 1½-in. has a high limit of +1·4 thousandths and a low limit of 0, and the Q shaft has a —1·1 thousandths high limit and a —2·1-thousandths low limit. Guided by these tolerances on the work, very little scraping should be necessary.

Terms such as B.U.V.W. holes and F.E.D.C. shafts should always be used in place of " Running Fit," " Push Fit," &c., which have no precise meaning.

When new bearings and shafts have to be made, the assembly drawing should be marked 1½ inch B.F., or whatever clearance, interference or transition fit is decided upon.

To fit a bearing, first mark the ends as machined (*see* Sec. **43**, para. 17), check for size, part them, try on journal and in housing, keeping the marked ends always together.

Next, drill and cut oil- or grease-ways (Pl. **19**, Fig. 5) (usually in top half), chamfer the inside edges of the parting faces, to within ¼ in. of the ends and round off sharp edges which would scrape the oil or grease off shaft when revolving.

If two or three bearings are concerned, bed in all bottom halves first taking care that they are right home and then line through (Pl. **23**, Fig. 6). Next, clean all journals, lightly rub some colouring lead on each, place bearings in position and turn shaft round a few times. Look for any high or low markings and pack up or scrape out as may be necessary. Changing the bearings round may be sufficient in some cases.

Now put on top half-brasses and caps as marked, screw all securing nuts down hand-tight with thumb and fingers and turn shaft by hand to check freedom. Note particularly that in the final adjustment the parting faces must meet, metal to metal, the requisite running clearance being obtained by scraping the bearing surface. If a bearing is tight a thin liner may be used between the parting faces, but this should seldom be necessary in new work.

When the shaft turns freely, add half a turn with spanner on each nut and again check for freedom. If shaft is still quite free, all the nuts may be screwed home.

The shaft must now be turned through a number of complete revolutions (if necessary, by means of a carrier or clamp) and the caps and top half-brasses then taken off and any high marks removed with a half-round or three-square scraper. Trouble is sometimes caused through the top half-brass being bruised when chipping the oil grooves.

Now clean all parts with a paraffin rag, lightly oil the journals and reassemble.

All bearing nuts must be locked, after screwing home by lock-nuts or split-pins or both.

10. **Marking out.**—Accurate fitting cannot be carried out unless the work be previously marked out correctly to

correspond with the dimensions as shown on the drawing. The common tools and appliances required are surface plates, straight-edges, scribing blocks (Pl. **18**, Fig. 12), scribers, centre-punches, squares, dividers, trammels, parallel strips and V blocks.

The *combination set*, illustrated in Pl. **21**, Fig. 3, is also very useful for marking out. It comprises square-centre and protractor heads, all used in conjunction with one steel rule.

When one face of a casting or forging has been filed true it can be used as a base upon which to construct the figure of the finished article.

The work is first set up on the surface plate either resting direct on the table or supported on parallel strips, V blocks or suitable packing. The surfaces on which marks are to be made are treated as in para. 1 above.

Horizontal lines are usually made with the scribing block, and vertical lines by means of a square and hand scriber (Pl. **19**, Fig. 7). When using a square, care should be taken that the base does not foul the work.

Points such as the intersections of surfaces or the centres of holes are found by using compasses, either of the wing type or of the bar or trammel type, by ordinary geometrical methods. All such points, when found by means of intersecting lines, are marked by means of a fine centre-punch, and a few punch marks should be made along every line to ensure its permanency, since the scribed lines are easily obliterated when handling or working upon the metal. Holes should be indicated as follows :—

i. By a clear centre-punch mark at their centres.
ii. By a scribed circle showing the actual diameter.
iii. By another circle, a little larger.
iv. By fine centre-punch marks showing the intersection of these two circles with the vertical and horizontal centre lines, Pl. **19**, Fig. 8.

11. **Completion of other surfaces.**—The work can now be removed to the vice again, and the remaining surfaces chipped and filed down to size. The scribed lines will be sufficient guide for chipping and rough filing until the work is about 0·01 inch oversize, after which more accurate methods of measurement will be necessary.

When any measurements are being made, it must be borne in mind that the first surface to be finished is the new datum to which other parallel surfaces should correspond. Similarly, the first surface to be finished in another plane becomes the datum for other surfaces parallel to that plane.

In order that any solid object may be completely determined in shape and size, three such datum-planes are necessary.

Corners will only be truly square if these datum-planes are truly at right angles. Therefore, great care should be exercised to ensure that the second datum is made truly square to the first, and, similarly, that the third is square to both the preceding ones.

The scribed lines alone are not sufficient to ensure this. Towards the completion of each surface the fitter's square should be frequently applied at many different places, and any error corrected by filing more heavily upon the *high* spots.

The square is best used by holding up the work between the eye and a good light, such as a window or lamp. Little light should be visible anywhere between the square and work, and that only as a nearly uniform streak.

It is essential that a surface once adopted as a datum shall not be touched again with a file. It will be observed that the first scribed lines are made upon the rough surface of the casting. As each face in turn is worked upon, the marks upon it will be removed. If any of these marks are required for guiding work upon other faces, the casting must be taken back to the marking-out table, and the missing lines scribed afresh, the casting standing upon the datum-plane to which the line should be parallel.

38. *Drilling, reaming and tapping by hand*

1. **Types of work.**—A fitter or driller must be able to drill holes accurately as regards position and direction, ream them accurately to size, tap them to any desired depth by means of taps, and spot face the work near the holes, when necessary.

A fitter must also be able to cut screws and bolts by means of stocks and dies.

2. **Drilling.**—Holes are normally drilled in a drilling machine or in a lathe, as described in Sec. **43**.

In the absence of a drilling machine, or if the nature of the work does not permit it to be placed on the machine, holes can be drilled by hand, using a drill post and ratchet drill for larger holes. Portable electric or pneumatic drills, which can be used with a drill post or in the hand, in the same manner as hand-operated drills, are great labour savers if the necessary power supply is available.

Care is required to maintain accurate direction with breast and ratchet drills.

The hole centre should first be marked with a scriber and a centre-punch. Then, with a pair of dividers, a circle is scratched upon the surface $\frac{1}{16}$ in. larger in diameter than that of the required hole. A few light centre-punch marks on the circle will be useful as a guide.

Since the lips of the drill slope back from the point, a shallow cup-like depression is first produced, whose diameter is less than that of the drill. The drill should now be withdrawn and this depression examined to ascertain whether it is central with the marked circle. If it is much out of the centre the depression should be cut central with a round-nosed chisel, or preferably a hand drill about $\frac{1}{8}$-inch diameter. This practice is commonly known as *drawing* the hole. The outside edge of the drill must not be allowed to reach the work till the depression is truly central.

An error of 0·01 inch in the position of a hole should not be permitted in ordinary work.

3. **Drills.**—There are numerous types of drill, but the fluted drill is the type normally used for all ordinary purposes. Occasions may arise, however, especially in the field, when a fluted drill is not available. In these circumstances *flat* drills may be found useful.

A flat drill can be knocked up quickly to any desired size, or an available flat drill may be altered in a few minutes, either by grinding or dressing. A flat drill may, if necessary, be given a glass-hard cutting edge which will stand harder usage than the average twist drill.

As there is nothing to keep the point central, however, this type of drill cannot be relied upon to drill straight holes and it can only be used for rough work.

Fluted drills are either *spirally* fluted (Pl. **19**, Fig. 12) or *straight* fluted (Pl. **19**, Fig. 11). Straight fluted drills are used for drilling soft materials such as brass and copper, and spirally fluted or *twist* drills for iron and steel. The spiral flutes enable the cutting edges to have rake, and thus reduce the amount of power required. The flutes also assist by their screwing action in removing chips from the hole and so facilitate the drilling of deep holes. This type of drill cuts fairly accurate holes, because the shank is guided by the first part of the hole drilled and the point is thus kept in line. Further remarks on drilling and instructions for grinding fluted drills are given in Sec. **45**.

4. **Reaming holes.**—A reamer is a finishing tool for trueing a hole that has been drilled to nearly the correct size. This is necessary because no drill can be relied upon to make a hole truly round, straight, and exactly to size. The drilled hole should be not more than about $\frac{1}{64}$ inch below the finished diameter, because a reamer cannot be expected to remain accurate long if it is subjected to the wear of removing much metal.

Pl. **19**, Fig. 13, shows a hand reamer. It is slightly tapered near the point to enable it to enter the drilled hole. The

remainder of its length is parallel if a parallel hole is required, or tapered if a tapered hole is required. The long parallel shank of a straight reamer is guided by the side of the hole as it works farther in, and so keeps the hole straight. If a blind hole is required to be parallel throughout its length, a parallel reamer, without end taper, must be used finally to cut out the bottom to size.

A reamer should be well lubricated (except in cast iron). It should be turned slowly by means of a key, K, with two equal arms. Equal force should be applied to both arms, so that there may be no bending stress on the reamer. If only one arm were used, the hole might not be trued in the required line, through being started askew, and would thus tend to bend and so cut too large a hole, or the reamer might be broken. The reamer should always be turned in the same direction. Instructions for grinding reamers are given in Sec. **45**.

5. **Tapping holes.**—Taps are reamers with threads upon their flutes, which cause them to leave a corresponding thread in the hole, Pl. **19**, Fig. 14. Since they must cut the full depth of the thread, and so must remove more metal than a plain reamer, the flutes are made deeper and wider to accommodate chips. One of the set also needs more taper than a plain reamer, since there must be more difference in the size of the tap and the drilled hole. Taps are normally made, therefore, in sets of three, viz. :—

i. Taper.
ii. Second taper.
iii. *Plug*, or parallel.

They should be used in this order, and in the case of very deep holes (i) and (ii) may advantageously be used alternately till (ii) reaches the bottom of the hole, when (iii) should be also used.

Taps should be worked backwards and forwards to clear the chips, taking a forward turn of about 180° clockwise, and then turning the tap backwards, counter-clockwise, nearly an equal amount.

Taps are very weak, because the screw thread and flutes leave only a thin core of steel to take any twisting or bending stress. They must, therefore, be used very gently and with plenty of oil (except in cast iron). If a tap binds at all, it should be screwed right out of the hole, and the hole should be cleared of chips before the tap is used again.

6. **Size of holes for tapping.**—The hole, as first drilled, should be twice the depth of a thread smaller in diameter than the screw it is to take. The depth of the Whitworth form of

thread is $0{\cdot}64 \times$ pitch. Thus, the drilling size for a 1-in. Whitworth thread, 8 to the inch, is $D - 1{\cdot}28p = 1 - \frac{1{\cdot}28}{8} = 1 - 0{\cdot}16 = 0{\cdot}84$; nearest fractional size $\frac{27}{32}$ in.

7. Stocks and dies.—Dies are tools working on the same principle as taps, but cut the male threads. For moderate sizes they usually take the form of a split nut with grooves cut through the threads to leave cutting edges and provide clearance for chips. Being short, they have little taper, so can only cut a shallow thread in one passage over the screw. They are then screwed back and closed slightly before taking the next cut. The *stock* is a special double-handed wrench for holding the dies, adjustable to take a range of sizes and to tighten the die on the work. (*See* Pl. **19**, Fig. 15.)

Dies should not be started upon the end of a bolt, but a little way down, to ensure that their axis is in line with that of the screw. The thread is cut by a backward and forward movement, as with a tap.

After several cuts, each the whole length of the screw required, the threads begin to assume the correct form. As soon as they begin to be rounded at the top, they should be gauged, either with the nut that is to go on, in the case of a bolt, or preferably with a hardened gauge nut.

If accurate standardization is required, it can be ensured by making the last cut with a die nut, Pl. **19**, Fig. 16, whose size will not alter appreciably in cutting a fairly large number of screws.

A die is made of tool steel. It has holes drilled in it which intersect the threads, providing cutting edges and also clearance for the chips.

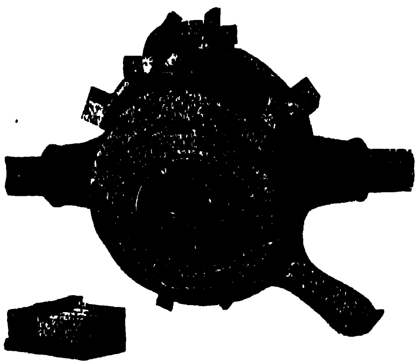
8. Die plates.—Very small screws are often made by means of a die plate, Pl. **19**, Fig. 17, which is a collection of die nuts, cut in one plate for convenience. For each size there are usually two holes, one tapered and the other parallel or nearly so. The rod for these small screws should be of a diameter of about $D - \frac{1}{2}p$. The metal to build up the thread to full diameter is provided by the squeezing action of the plate. The rod should be slightly tapered at the extreme end to allow it to enter the taper hole.

9. Large dies.—Dies for large diameter threads, such as pipe threads, usually consist of four or more narrow segments, each with one cutting edge and no grooves, the space between the segments providing the clearance. These are carried in stocks of special design, allowing the dies to be adjusted simultaneously by one movement.

Pl. **20**, Fig. 1, shows a Hart "Duplex" die stock for pipe threads up to 2 inches. Fig. 2 shows a "Beaver" die stock for

PLATE 20.

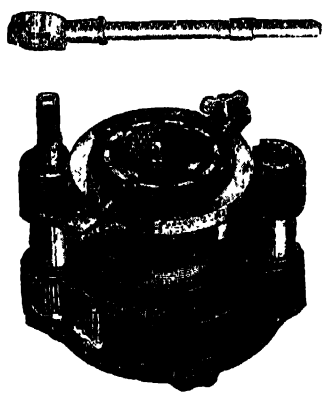
HART DUPLEX DIE STOCK



[*Permission of Messrs. W. H. Willcox & Co., Ltd.*]

Fig. 1

BEAVER DIE STOCK



[*Permission of Messrs. Buck & Hickman, Ltd.*]

Fig. 2

pipe threads from $2\frac{1}{4}$ to 4 inches. The latter has a geared down ratchet drive which, besides giving the necessary mechanical advantage to allow one man to screw a large pipe in one cut, allows the die stock to be used in a confined space (*e.g.* a pipe trench). Another feature of the "Beaver" die stock is the use of a lead-screw to guide the rotating portion of the stock on the proper thread, the usual practice being to allow the dies to guide themselves. The lead-screw makes for greater accuracy, especially with long threads.

39. *Measuring and gauging*

1. **Measuring instruments.**—Instruments for measuring the thickness, length, &c., of the work, to ensure that the correct form is being built up upon the chosen datum-planes, consist of :—

i. Callipers.
ii. Gauges.

2. **Common hinged-callipers.**—Pl. **19**, Fig. 18. There are two types of these, one for measuring outside of work and the other for measuring inside. They are used as follows :—

i. By opening the callipers by hand so that they will roughly fit over or go into the work to be measured.
ii. By gently tapping one leg against a bench ; the callipers are thereby made to get a better fit over or into the work.
iii. The final fit is best obtained by a screw adjustment ; ordinary callipers, however, are not fitted with this.

Accuracy can only be obtained with these instruments by care in holding them so that the points truly touch opposite spots on the surface of the work, and by cultivating a sense of touch. The points must not be forced on to the work. The callipers must be so adjusted that the points touch with a slight drag only, because any pressure would spring the points a little. They would then spring back when removed, and the measurement made would be inaccurate.

The distance between the points, when satisfactorily adjusted to the work, is measured by a finely-divided steel rule, Pl. **19**, Fig. 19. Measurements made in this way are rough, and cannot be relied upon to give a reading to within 0·01 inch of accuracy.

A more accurate method is to compare the work with a standard made of a piece of metal, generally a block of hardened steel, ground accurately to dimensions, by applying the callipers to the work and standard in turn ; a difference of 0·001 inch can thus be felt. Two or more such standards may be placed together to make up any desired thickness.

3. **Vernier callipers.**—Pl. **19**, Fig. 20, shows a sliding calliper (N.I.V.) fitted with a vernier, V, by means of which measurements can be made to within 0·001 inch of accuracy.

The calliper should be gently closed upon the work, and should slide off without binding but with a distinct feeling of *drag*. A screw adjustment, S, assists greatly in obtaining the setting. The divisions upon the vernier scale are 0·001 in. smaller than those upon the calliper scale or rule. Therefore, if the 0 mark upon the vernier is a little beyond a division, A, upon the rule and the 1 mark is level with the next division, the 0 mark must be 0·001 in. beyond A. If the second mark corresponds with a division on the rule, the 0 mark must be 0·002 inch beyond A.

To read the vernier, write down the measurement indicated by the rule division A before the 0 mark on the vernier in decimal form thus, 0·025. Count the vernier divisions up to that one which best corresponds with a division on the rule, and write down the number of thousandths which this shows the 0 mark is beyond A, thus 0·011 (the eleventh division being the best lined with one on the rule). Add these two figures, thus, 0·025 + 0·011 = 0·036, which is the required measurement.

4. **Micrometer callipers.**—Pl. **19**, Fig. 21, and Pl. **21**, Fig. 1, show a micrometer, or screw, calliper, which is considerably more accurate than the sliding vernier type. The screw has a milled head, A, and sometimes a second ratchet head, which slips at a definite pressure, and so enables a man who has little sense of touch to screw down the calliper on to the work without any risk of straining it, and always with the same pressure, viz., that at which the ratchet slips. The sleeve, S, in which the screw turns, is graduated, generally in fortieths of an inch, *i.e.* at every 0·025 in., and this is the pitch of the screw. The head of the screw is divided into 25 equal parts by marks on the bevelled edge, and these are numbered backwards ; each represents 0·001 in.

Inside micrometers, for measuring the diameters of cylinders, &c., and micrometer depth gauges are calibrated in the same manner.

When the calliper has been removed from the work the reading is interpreted as follows :—

Multiply the number of whole spaces visible on the barrel by 25, add the number of spaces between the zero line of the thimble and the line coincident with the line of graduations on the barrel. This gives the result in thousandths of an inch.

Examples of micrometer readings are given in Pl. **21**, Fig. 2.

Plate 21.

FITTERS TOOLS.

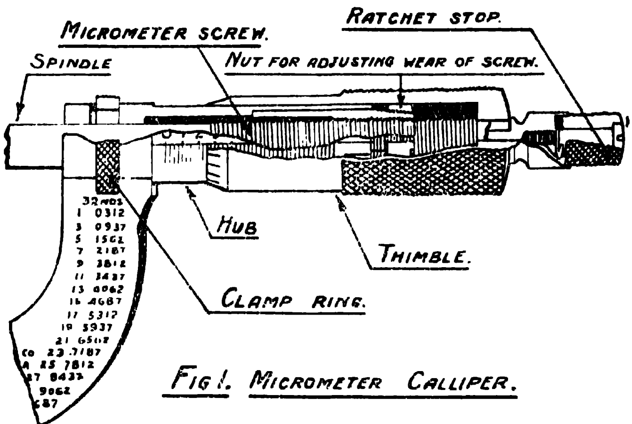
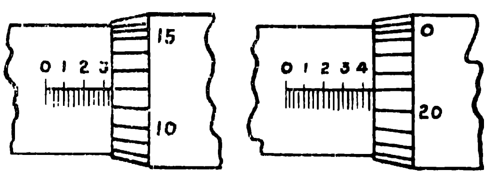


Fig 1. Micrometer Calliper.



0·337 0·446

Fig 2. Micrometer Readings.

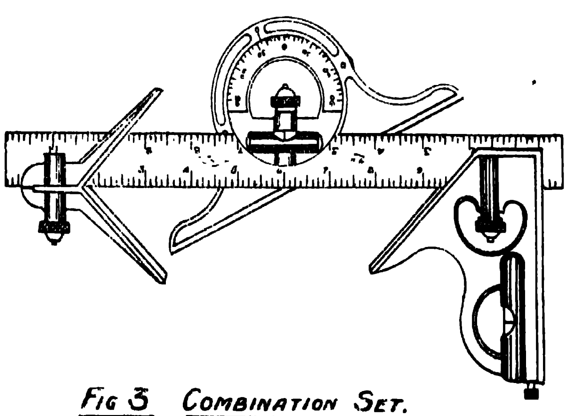


Fig 3 Combination Set.

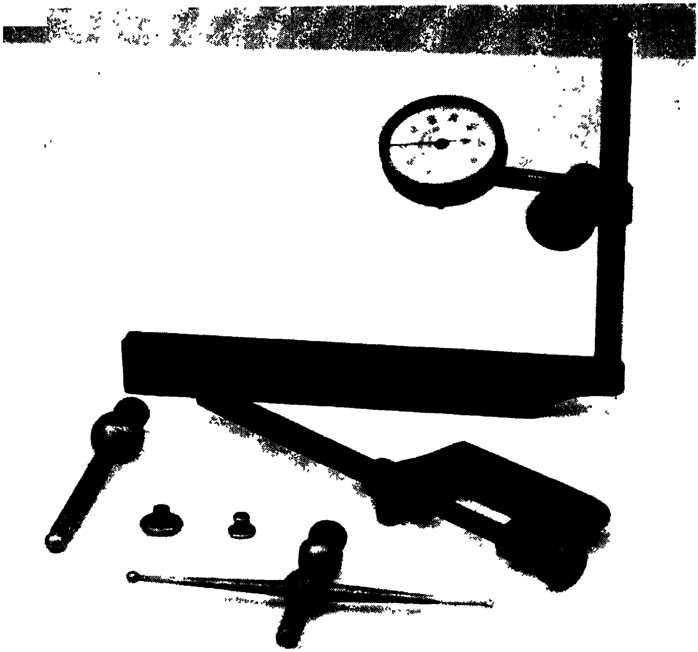


Fig. 1.

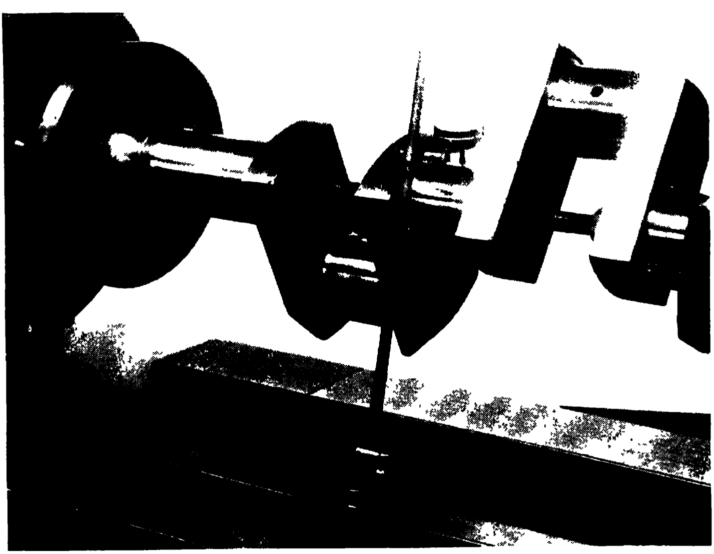


Fig. 2.

It will be noticed that whereas with the sliding vernier calliper it is often difficult to decide which of the divisions correspond best, there can be no doubt with the micrometer calliper, whose divisions are so distinct that a fairly accurate determination can be made of the number representing 1/10,000 in., and the size of the work could be expressed at 0·0402 in., with only a slight doubt as to the last figure.

The foregoing procedure must always be followed when measuring. On no account must a micrometer calliper be set to a stated size and then be pushed on or into the work; the instrument would be permanently damaged by such treatment, and the measurement obtained would not be accurate.

The instrument may be calibrated by making it read 0 when the points have been brought gently together. A means of adjustment is generally provided, either in the nut or in the anvil or fixed point, P. If no adjustment is provided and there is an error, the amount should be noted and the correction applied to every reading.

5. **The dial test indicator.**—This indicator is specially serviceable to fitters and engine erectors, for determining the inaccuracy in a surface, or the movements of a spindle or arbor.

Pl. **22**, Fig. 1, shows a dial test indicator, mounted on a horizontal arm, and Fig. 2 illustrates one of its uses. *See also* Pls. **89** and **91**.

The dial indicates thousandths of an inch, and the zero can be set to any desired position. The spindle of the dial indicator usually has a maximum movement of about ½ in.

6. **Gauges.**—When a large number of articles of the same dimensions has to be turned out, fixed measuring instruments may be used, which are known as gauges.

Pl. **19**, Fig. 22, shows a gauge of the type known as a limit gauge. It is not possible to make any article exactly to size, and an error of 0·001 in., 0·002 in., or more, according to the required accuracy or the skill of the workman, is usually permitted.

Having decided the amount of permissible error above and below the theoretical size, a limit gauge with two gaps, one a little larger than the other, can be made. The larger gap, often stamped GO, should slide easily on to the work; the other, marked NOT GO, should not fit on to the work.

Gauges must on no account be forced on to the work. Not only would the indication be useless, but the gauge would be permanently damaged.

Gauges are made generally of tool steel, filed and scraped or machined nearly to size while soft. They are then hardened, and afterwards lapped to the required size as

accurately as possible with emery and oil, and then with an oilstone.

Pl. **19**, Fig. 23, shows an external and internal gauge, A, for measuring a shaft or pin, and the hole, B, in which it is to fit. In such a standard 2-in. gauge intended for engine work, A might actually measure 2 in., and B should then be larger, *e.g.* 2·003 in. The shaft must then be at least 0·003 in. smaller than the hole if it will go into A, and B will enter the hole. It does not follow, however, that the clearance between the shaft and the hole will be only 0·003 in. It may be much more.

If both work and gauge are smooth and parallel, an experienced man can judge by the amount of pressure needed to apply the gauge what difference there is between the work and gauge. It is better for men of low skill, especially where good standardization is required, to use limit gauges for both the shaft and the hole.

40. *Standard limits, fits and tolerances*

1. **British standard fits.**—The British Standards Institution has published a specification (No. 164 of 1924) of standard limits and fits for engineering. A chart, No. 164B, gives the actual tolerances of hole and shaft in a form suitable for posting in a workshop.

The British Standard Holes are listed in the chart in three groups, as follows :—

(*a*) *Unilateral,* in which the nominal size of the hole is the low limit, the tolerance being always a plus amount.

(*b*) *Bilateral,* in which the nominal size of the hole lies between the high and low limits, the tolerance being plus and minus.

(*c*) *Oversize,* in which the low limit of the hole is larger than the nominal size.

In each group three or four grades of workmanship are provided for, each grade being identified by a letter. Thus a " B " hole is a unilateral hole of the highest class of workmanship, the tolerance on a 3-in. hole being only 0·9 of a thousandth of an inch. A " U " hole has a tolerance of double this amount, a " V " hole has double the tolerance of a " U " hole, and a " W " hole double this again.

The chart gives a table of British Standard Shafts and their limits, the same shafts being used for either a unilateral, a bilateral, or an oversize hole. This table gives fourteen pairs of high and low limits for each nominal size of shaft, and the fit is determined by the particular pair selected, the

hole being the constant once the class of workmanship has been decided.

The Specification recommends :—

i. That the unilateral system be adopted.

ii. That old terms such as " drive fit," " push fit," and " running fit " be abandoned, and be replaced, where classes of fit have to be described in general terms, by the expressions :—

(a) *Interference fit,* where there is a negative allowance (obstruction) between the largest possible hole and the smallest possible shaft, the shaft being the larger.

(b) *Transition fit,* where the limits allow of either an interference or a clearance fit being obtained.

(c) *Clearance fit,* where there is a positive allowance between the largest shaft and the smallest hole.

The hole most commonly used in engineering practice is the " U " hole (unilateral system). The chart includes a table in which the fits of the fourteen shafts in a " U " hole are compared with the fits formerly described as drive, push, or running fits. Thus, what used to be called a push fit is equivalent to the fit of a " K " shaft in a " U " hole, which is a transition fit.

By the adoption of the British Standard system, vagueness is abolished and accurate interchangeability is made possible.

Gauges for workshop use must have their own tolerances *within* the limits laid down for the work, in order to ensure that no work is passed out which falls outside the limits specified in the table.

41. *Overhaul of steam engine slide valve*

This operation is taken here as an example of fitters' work. Further examples will be found later in the book as below :—

Sec. **49.**—Testing machine tools.

Sec. **102.**—Routine, inspection and maintenance of Diesel engines.

Chap. XX.—Overhaul of I.C. engines.

Sec. **148,** paras. 7, 8 and 9.—Erection and overhaul of line shafting.

1. **Adjusting slide bars.**—The slide bars of a steam engine wear hollow in the centre, and should be trued upon a surface grinder. Otherwise they may be trued by lapping

down with emery cloth wrapped round a file and oiled. They should be fitted to a face-plate or wide straight-edge. After grinding the bars, their sharp corners should be filed off to avoid damage to the hands while assembling them. Normally one bar will hang on its studs, while the other will rest on the frame casting on its original packing. The piston should be placed in the cylinder and keyed to the crosshead, Pl. **23**, Fig. 7. The bars are then lined up as follows :—

i. The crosshead is placed successively at each end and the middle of its stroke, and the following particulars should be noted in each position :—

(*a*) Whether the piston rod is central in the gland, and, if not, the direction and amount of eccentricity.
(*b*) Whether the crosshead surfaces are in good contact with the bars throughout, shown by smearing the bars with grease and observing the trace of the slide blocks on the grease.
(*c*) Whether the vertical faces of the crosshead at the gudgeon pin are true, *i.e.* at 90° to the line of crankshaft.

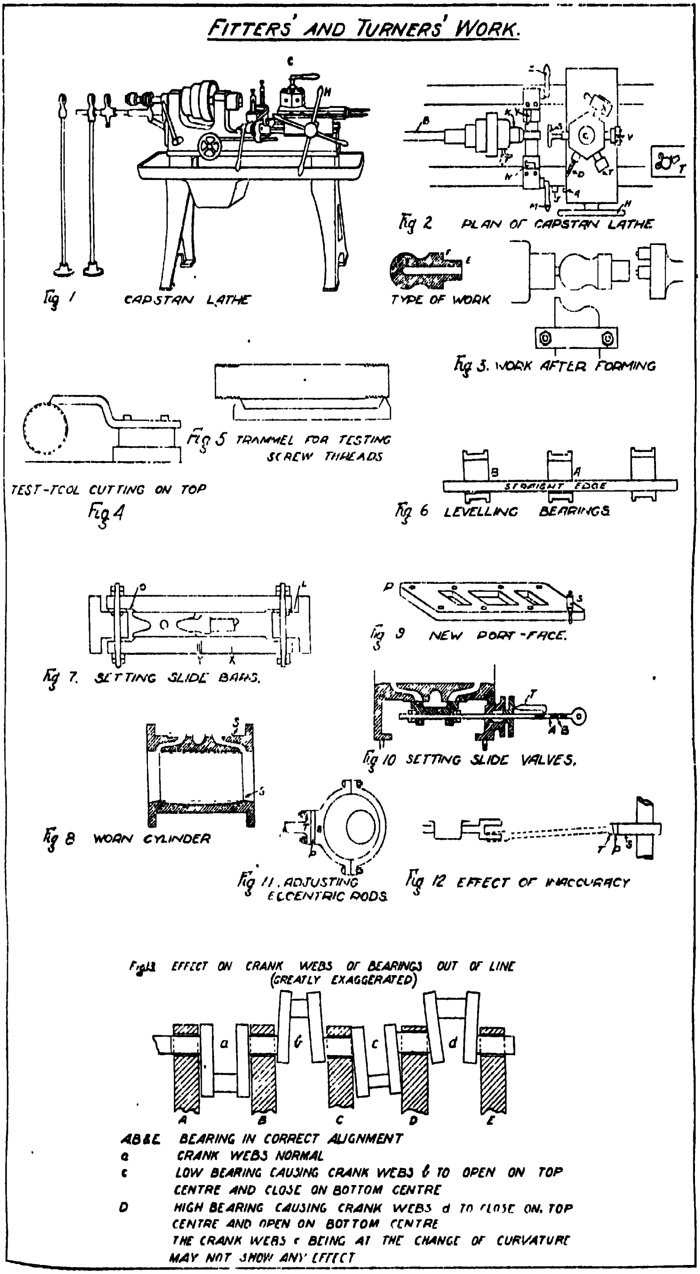
ii. Liners, or thin plates of metal, L, are placed between the bars and their seatings, chosen to correct the observed errors as well as possible, the retaining nuts are tightened, and the tests in (i) are repeated.

Any errors still observed should be corrected by filing the liners, or adding more thin plates, till the alignment is satisfactory. For the final test the slide block surfaces should be coloured with red lead, and moved from end to end. The following effects should be obtained :—

(*a*) The piston rod should keep in the centre of the gland throughout the stroke.
(*b*) Red lead smears should show upon all bars throughout their length, and be reasonably even all over their surfaces.
(*c*) A straight-edge placed through the gudgeon pin seating should remain parallel with the crankshaft throughout the stroke.
(*d*) There should be little tendency to binding between the crosshead and bars. Binding in the centre is of little importance, because the bars will spring. Any binding at the ends, where the bars are rigidly held, must be corrected by lapping.

iii. The slide blocks must be given overrun by filing away the bars as shown at O. Otherwise the bar would wear and leave a shoulder or hump at the end, which would cause knocking.

PLATE 23.


FITTERS' AND TURNERS' WORK.
Fig 1 CAPSTAN LATHE
Fig 2 PLAN OF CAPSTAN LATHE
TYPE OF WORK
Fig 3. WORK AFTER FORMING
TEST-TOOL CUTTING ON TOP
Fig 4
Fig 5 TRAMMEL FOR TESTING SCREW THREADS
STRAIGHT EDGE
Fig 6 LEVELLING BEARINGS
Fig 7. SETTING SLIDE BARS.
Fig 9 NEW PORT-FACE.
Fig 10 SETTING SLIDE VALVES.
Fig 8 WORN CYLINDER
Fig 11. ADJUSTING ECCENTRIC RODS
Fig 12 EFFECT OF INACCURACY
Fig 13 EFFECT ON CRANK WEBS OF BEARINGS OUT OF LINE (GREATLY EXAGGERATED)
A B C D E
AB&E BEARING IN CORRECT ALIGNMENT
a CRANK WEBS NORMAL
c LOW BEARING CAUSING CRANK WEBS b TO OPEN ON TOP CENTRE AND CLOSE ON BOTTOM CENTRE
D HIGH BEARING CAUSING CRANK WEBS d TO CLOSE ON TOP CENTRE AND OPEN ON BOTTOM CENTRE
THE CRANK WEBS c BEING AT THE CHANGE OF CURVATURE MAY NOT SHOW ANY EFFECT

2. Re-facing slide-valve ports.—The face upon which the slide valve of a steam engine moves wears down and requires attention to the following points :—

i. The face may be hollowed or grooved, so that steam escapes between the valve and its seating. This can be corrected as follows :—

(*a*) If the inaccuracy is small, by scraping both valve and seating to a face-plate, as described in Sec. **37**, para. 8, and then to each other.

(*b*) If the inaccuracy is large, by re-surfacing in a shaping machine or surface grinder if available, and finishing by scraping, as in (*a*).

ii. The face may have worn down in the centre, leaving a shoulder, S, at one or both ends, Pl. **23**, Fig. 8. This causes knocking, and may also allow steam to escape, producing loss of power in the engine and heavier fuel consumption. The shoulder should not merely be removed, but should be cut well down by chipping and filing, so that the valve distinctly overruns the working face. This will ensure that a fresh shoulder will not be soon worn. *See* Pl. **23**, Fig. 10.

iii. The face may have worn down so that the wall between the passages and the face is too thin, and the form of the ports may have become inaccurate. This can only be remedied by fitting a new face, as follows :—

(*a*) The face is smeared with red lead paste, and a sheet of paper is pressed down on it to give a colour template showing the ports *as they are.*

(*b*) A drawing is made from this template, showing the ports *as they apparently should be.*

(*c*) A wooden pattern is made to the drawing, and from this a plate of hard cast iron is cast.

(*d*) The plate, P on Pl. **23**, Fig. 9, is machined on both sides, the ports in it are cleaned out by filing, and one side is scraped to fit the old face, or vice versa.

(*e*) Holes are drilled in the new face to take tapered peg screws, S, being carefully placed so that they will have a good hold in the solid metal of the old face.

(*f*) Tapping holes are drilled in the old face, using the new one as a template, and then tapped.

(*g*) The peg screws are driven hard home, nicked with a hacksaw, broken off, and filed down flat. A little red lead between the faces will improve the joint.

(*h*) The new face, which may have been distorted in screwing it down, is scraped to fit a surface plate.

(*i*) The valve is scraped, first for convenience to fit a surface plate, and then to fit the new face accurately.

3. **Errors in slide valves.**—When re-erected, the slide valves of an engine are certain to be inaccurate unless great care is taken to adjust them. *The whole object of an overhaul will be lost unless the valves are accurately set.*

The normal errors found, after an overhaul, are as follows :—

i. The ports do not open equally at both ends of the travel of the valve. Variation may have occurred due to :—

(*a*) Re-bushed holes for pins being at slightly altered distances.

(*b*) Rods straightened being a little drawn out in the process.

(*c*) A new valve having a slightly different shape from the old one.

(*d*) Re-faced ports not being quite in the old places.

(*e*) No allowance having been made in semi-portable engines for expansion of the boiler, the valves having been set when cold.

ii. The time of admission, cut off, and exhaust may have been considerably altered, owing to :—

(*a*) Slight differences between the new valves and faces and the old ones, giving a different amount of lap.

(*b*) Errors in setting eccentrics, *i.e.* in angular advance.

4. **Setting slide valves.**—To set a valve, the rod should be smoked with a candle, a trammel made, as shown at T on Pl. **23**, Fig. 10, and placed with one of its points resting in a centre-punch mark on the valve gland. The procedure is then as follows :—

i. The crankshaft is rotated until one port is in the position of *cut off*, ascertained by the grip on a strip of thin sheet metal held in the port. A mark, A on Pl. **23**, Fig. 10, is made on the smoked rod with the trammel, and the angle of the crankshaft is noted, or a mark, X on Pl. **23**, Fig. 7, is made upon a slide bar, level with one end of the main side block.

ii. The shaft is slowly rotated backwards. As the valve nears the end of its stroke, the trammel is kept marking the rod until the valve commences to return, the extreme mark made being shown by B. The distance between mark A, made in (i), and mark B is the amount of the opening of the valve.

iii. Operations (i) and (ii) are repeated for the other end of the travel of the valve.

The two amounts of opening are compared by careful measurement.

In the case of an engine on a bed which is likely to remain at the same temperature as the rods, the two openings should be the same.

In a portable or semi-portable engine in which the boiler is also the engine bed, allowance must be made for the expansion of the boiler under steam, thus :—

Length, from middle of cylinder block to crankshaft, L inches.

Temperature difference, between rods and boiler, T° F.

For example, the probable temperature of the rods will be 120° F. and that of the boiler at 150 lb. 360° F. The difference T° will be 240° F.

Expansion allowance is $L \times T \times 0{\cdot}000007 = E$.

For example, if L is 100 in. and T is 240° F., then $E = 240 \times 100 \times 0{\cdot}000007 = 0{\cdot}17$ in.

In this case, the port nearer to the crankshaft should be adjusted to have an opening, when cold, of 0·17 in. more than the average of the two, *i.e.* of 0·34 in. more than the opening of the farther port. When the boiler is heated, it will expand 0·17 in., and will add that amount to the opening of the farther port, and take it from the nearer one.

iv. Adjustment can be made in two different ways.

(*a*) Many valve rods have nuts which locate the position of the valve, as shown on Pl. **23**, Fig. 10. The nuts on that side which has too much opening should be slacked back the required amount, and those on the other side screwed forward to the valve.

The nuts must not grip the valve, or it cannot seat itself upon the face without bending the rod.

The lock nuts must be well tightened, or the setting will alter when the engine is running.

(*b*) More or less packing, P on Pl. **23**, Fig. 11, can be placed between the eccentric strap, S, and the cross, T, of the eccentric rod. Care must be taken that the packing is of even thickness, or the rod will be thrown out of line and will wear its pins rapidly.

The other end of the rod, when free, should fall naturally into correct line with the valve rod.

On Pl. **23**, Fig. 12, some springing would be needed to place the rod in line, owing to inaccurate packing.

v. The eccentric sheave may need adjustment. Eccentric sheaves may become loose through wear on key or keyway, necessitating a larger key.

In many semi-portable engines the eccentrics are adjustable, being held in position by a bolt against a plate or lug on the shaft.

In the former case, the sheave should be temporarily fixed to the shaft, by bolting the halves together sufficiently tightly to operate the valve without slipping, and the effect

tested as follows, the link gear being in full forward position:—

(*a*) Smoke or colour the side of a slide bar, and ascertain the travel of the crosshead by revolving the crank-shaft slowly near each dead centre, making marks for the position of one end of the crosshead, Y on Pl. **23,** Fig. 7. The farthest mark made indicates the limit of travel.

(*b*) Compare Y with the mark X made in (i) indicating the point of cut off. This should normally be at about half stroke.

(*c*) Obtain marks similarly, by revolving the shaft backwards from dead centre until a thin strip of metal is gripped in the inlet port, at either end in turn, to show the point of inlet. This should normally be about 1/20 stroke before dead centre, the crank being from 20 to 30° from the dead centre position, this being the angle of lead. For a high-speed engine the lead may be more, probably 40 to 45°.

(*d*) When these observations are satisfactory, the position of the eccentric must be marked by scribed lines on the shaft and sheave. The new key can then be fitted to hold the sheave.

(*e*) If a reverse eccentric is provided, it should be located similarly with the link lever in full reverse position.

(*f*) At the first opportunity, indicator diagrams should be taken with the engine running at normal speed and at a suitable load in full forward, in full reverse, and in half-forward gear. These diagrams will show if any error has been made in setting.

For Bibliography, see page 687.

CHAPTER IX

MACHINE-SHOP WORK

42. *Machines and tools*

1. **Machine tools.**—Machine tools for working on metal are designed to perform much the same operations as hand-fitting. They are used to save time and cost of production, as they enable more power to be applied than a man can apply with hand tools. Further, since either the tool or the work (whichever is made to move) is guided by metal slides, the degree of manual skill required from the operator is less. His skill is shown not so much by the accurate movements of the hands, which require long practice to achieve, as by his competence in setting both work and tools to obtain satisfactory results.

Machine tools fall naturally into three main categories :—

i. Those employing tools with one cutting edge only, analogous to the chisel or scraper. Examples are lathes, boring machines, planers, shapers, and slotters.

ii. Those employing a series of cutting edges, analogous to the file. These include all types of milling machines, broaches, drills, and reamers.

iii. Grinding machines, using wheels of emery, carborundum, &c.

2. **Cutting tools.**—*Angles.*—All cutting tools, whether for use by hand or in a machine, and whether they have only one cutting edge or many, are designed upon the same principles.

On Pl. **24,** Fig. 10, X illustrates a cutting tool removing a shaving of metal and leaving a fair surface behind it.

It will be obvious by comparing it with Y that the tool can only cut properly if the extreme edge, and nothing else, is in contact with the finished surface. In consequence, it is necessary to grind the heel of the tool to the angle A, known as the relieving angle, which must be carried right through to the cutting edge. The angle B, known as the tool angle, forms the wedge which separates the chip or shaving. Obviously, the more acute this angle, the less power will be needed to drive the tool through the material, but the tool

will be correspondingly weaker and its edge more easily broken off.

The angle C, known as the angle of rake, provides the separating force which turns the chip away or breaks it off. An equal reaction is produced which tends to drive the edge farther into the work. There is always a certain amount of spring in both tool and work, and also some backlash in the screw which adjusts the position of the tool ; in order to force the tool into the work to begin cutting, considerable pressure must be applied by this screw.

If there is too much rake, the reaction of the chip when cutting begins may equal or exceed the pressure between the edge of the tool and the finished surface. In this case the spring in the work and tool will force the latter farther into the former, and it may be drawn in still farther by the reaction of the chip. Then the *spring* will act the other way, and will eventually break the chip or tool. The tool will spring out again, and the cycle will recommence.

This effect is known as *digging in* if the tool breaks or the machine is stopped, and *chatter* if the tool springs out unbroken and continues cutting in jerks.

In either case the finish of the work is not good, the tool and machine suffer, and the power absorbed may be increased.

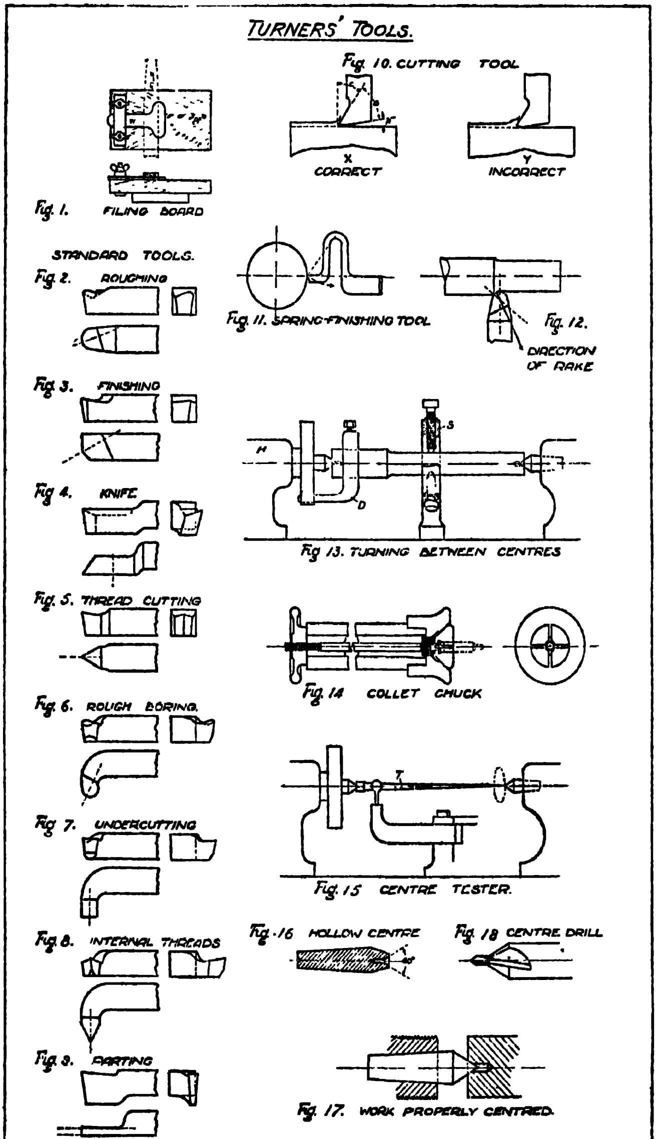
This defect may be overcome by increasing the tool angle, *i.e.* by diminishing the rake or relief, or both. It is better to avoid it and ensure the utmost rigidity by fixing a travelling steady on the saddle immediately behind the work and tool, or by so designing the tool that any increase in resistance, sufficient to cause springing, draws the edge slightly out of the work. The latter principle is illustrated on Pl. **24,** Fig. 11, which shows an old-fashioned spring tool for light finishing cuts.

The angles found suitable for the most common materials are given in the following table :—

Material or work	A (relief)	B (tool angle)	C (rake)
	Degrees.	Degrees.	Degrees.
Wrought iron and mild steel	5	60 to 70	15 to 25
Soft cast iron	5	70	10
Hard cast iron	5	85	0
Cast and alloy steels ..	5	70	15
Brass and gunmetal ..	5	85 to 90	0 or negative.

3. **Form of tools.**—Pl. **24,** Figs. 2 to 9, illustrate some common forms.

PLATE 24.


TURNERS' TOOLS.
Fig. 1. FILING BOARD
STANDARD TOOLS.
Fig. 2. ROUGHING
Fig. 3. FINISHING
Fig. 4. KNIFE
Fig. 5. THREAD CUTTING
Fig. 6. ROUGH BORING.
Fig. 7. UNDERCUTTING
Fig. 8. INTERNAL THREADS
Fig. 9. PARTING
Fig. 10. CUTTING TOOL
X
CORRECT
Y
INCORRECT
Fig. 11. SPRING-FINISHING TOOL
Fig. 12.
DIRECTION OF RAKE
S
H
D
Fig 13. TURNING BETWEEN CENTRES
Fig. 14 COLLET CHUCK
T
Fig. 15 CENTRE TESTER.
Fig. 16 HOLLOW CENTRE
Fig. 18 CENTRE DRILL
Fig. 17. WORK PROPERLY CENTRED.

These few forms, made right-handed or left-handed as desired, will do all ordinary lathe and planing-machine work required in a service machine shop.

It will be noted that the tools shown in Figs. 4 and 9 cut on one edge only, while the others cut both on the nose and side. It is essential that the angle of rake, suitable for the material, should apply to every edge that cuts. Where two edges do equal cutting, this can be ensured by grinding the top so that its line of greatest slope bisects the angle between the two edges, Pl. **24**, Figs. 3 and 12.

This method of grinding also causes the actual edges of the tool to slope, and, therefore, little rake should be given. The relieving angle should never be omitted. This angle can always be put on the tool, whatever its shape.

It is essential that tools should always be ground by a man who understands the principles. Therefore, only highly skilled turners and fitters should be entrusted with this work.

In shops large enough to warrant the provision of a tool-room, only the toolmaker should be allowed to grind tools, and he should be carefully selected for his knowledge and skill. A card showing the angles for various metals should be hung near the grinder. Enlarged drawings show them best ; mere statements of angles mean little to the average man.

All tools should be standardized and the somewhat common practice of grinding tools to unauthorized shapes should be strictly forbidden. Special tools will sometimes be necessary. In such cases, a special order, with sketch, signed by an officer or the shop foreman should be given to the toolmaker as his authority to make the tool required.

The standards must include :—

i. A complete set of tools for mild steel.

ii. A complete set of tools for cast iron and tool steels.

iii. A complete set of tools for brass.

Gauges should be available when grinding tools and in a large shop it is advisable to fix a complete set of standard tools to a board, on which should be marked the angles, the name of each tool, and the material the set is to cut.

4. **Cutting speeds.**—The rate at which a tool removes metal is determined by the product of the cutting speed, the depth of cut, and the traverse, *i.e.* the width of the turning or chip.

i. The permissible depth of cut and traverse depend upon the rigidity of the machine and work, and also upon the material. They are determined by the largest area of metal that will be entirely crushed under a pressure that can be exerted by the machine without undue spring in the work and tool. Naturally, large machines are more rigid than small ones, and they can generally stand heavier cuts.

The cutting speed is decided chiefly by the rate at which the heat generated by the cutting can be conducted away; this varies with differences of temperature. Therefore, the cutting speed may be increased by :—

(*a*) Providing in the work and tool an ample metal path for the heat to flow away from the tool edge.

(*b*) Diminishing the amount of heat generated by carefully attending to the form of the cutting edge and by lubricating the paring edge.

(*c*) Cooling the tool with a good pump supply of metal cutting compound.

(*d*) Allowing a higher temperature (and hence a greater heat flow) at the tool edge by using a *high-speed tool steel*, which will retain its hardness at a temperature which would draw the temper of a simple carbon steel.

(*e*) Providing several different edges, any one of which will only cut for a short time and then has time to cool down while the others operate in succession, as in a milling cutter or a circular saw.

(*f*) Suitably treating the work before machining, *e.g.* high carbon steel may be annealed before machining to soften it, and hardened again if necessary when the machining is complete. Iron castings may have their hard skin removed by *pickling* or heat treatment may be applied.

Of these methods, (*a*), (*b*), (*c*), and (*f*) can be applied in any shop, (*d*) is of little value in machines designed for carbon steel tools, and (*e*) is more a matter of choice of the type of machine.

ii. The greatest output of metal removed by a machine per horse-power hour supplied should be obtained by setting the largest cut and traverse that the nature of the work and capacity of the machine will allow and using a correspondingly low speed, but only experience can tell which are the best conditions for working.

iii. A sharp point on a tool wears out sooner than the rest of the edge. Roughing tools for heavy cuts must, therefore, be well rounded to equalize the wear throughout the edge as nearly as possible.

iv. The formula given below for lathe tools applies only to heavy cuts made slowly with a roughing tool. For light finishing cuts, the speed should be half that given by the formula and never more than the maximum given.

Cutting speed, maximum feet per minute	=	V
Area of chip (depth of cut × traverse per rev. in square in.)	=	A
Constant depending on metal worked and tool steel used	=	C

$$V = \frac{C}{\sqrt[3]{A}}$$

Values of C, using carbon steel tools, are :—

For soft steel or wrought iron	4·5
„ hard steel	2·6
„ soft cast-iron	3·2
„ hard cast-iron	1·9
„ medium bronze	4·4
„ soft brass	9·0

For high-speed steel tools, these values may be doubled.

Table **K** gives cutting speeds for different tools and conditions. It is based on the formula given above, but corrected for the lighter cuts. The speeds given are for carbon-steel tools, and may be doubled for high-speed steel tools.

Example.—To find the speed for roughing 2-in. round mild steel bar in a lathe to $1\frac{3}{4}$ in., *i.e.* cut $\frac{1}{8}$ in., using $\frac{1}{16}$ traverse, with carbon steel tool.

$$A = \frac{1}{8 \times 16} = \frac{1}{128}, \ \sqrt[3]{A} = \frac{1}{5}, \ C = 4 \cdot 5$$

$V = \frac{C}{\sqrt[3]{A}} = 4 \cdot 5 \times 5 = 22 \cdot 5$ feet per minute. 2-inch round bar is about 6 inches or 0·5 feet in circumference. Therefore revolutions per minute of work $= \frac{22 \cdot 5}{0 \cdot 5} = 45$.

5. Particulars to be given when demanding machine tools.—When submitting a demand for a machine tool, the fullest possible information should be given as to the general purposes for which it is required and whether for ordinary or high-speed work.

The method of driving should be stated, and if from line shafting the diameter and speed of shaft given. If from an existing driving pulley, the speed, diameter, and width of this will be required ; if motor drive, full particulars of electric supply available.

TABLE K.—*Cutting speeds of various tools (in feet per minute)*

	Soft steel or wrought iron	Hard steel	Soft cast iron	Hard cast iron	Medium bronze	Soft brass
Lathe tool, area of cut $\frac{1}{64}'' \times \frac{1}{64}''$. (Maximum speed for finishing cut)	40	24	32	20	50	100
Lathe tool, area of cut $\frac{1}{16}''$ deep $\times$ $\frac{1}{64}''$ traverse ..	34	20	26	15	35	70
Lathe tool, area of cut $\frac{1}{8}''$ deep $\times$ $\frac{1}{32}''$ traverse	23	12	17	10	20	47
Planer, roughing cut	48	25	48	36	65	80
,, finishing cut	48	45	35	28	65	80
Cylindrical milling cutter (average figure). (Circumferential speed of teeth)	60	33	60	18	80	112
Face milling cutter	32	27	40	12	60	90

A list of any accessories specially required and the following leading particulars should be furnished :—

Lathes	Type of headstock.
	Height of centres.
	To admit in length between centres.
	Gap in bed.
	Whether screw-cutting gearbox is required.
	Face-plates, chucks, &c. required.
Planers	To plane in width.
	To plane in length.
	To plane in height.
Shapers	Length of stroke.
	Longitudinal traverse.
	Size of table.
	Dividing head required.
Slotters	Length of stroke.
	To admit in diameter.
	To admit in height.
Drilling machines	Type of machine (radial, pillar, or sensitive).
	Largest hole to be drilled.
	To admit in diameter.
	To admit in height.
	Radius of arm of radial machine.
Milling machines	Horizontal or vertical.
	Transverse traverse.
	Longitudinal traverse.
	Vertical adjustment.
	Dividing head.

A *Universal* miller is an expensive type of machine, but is very frequently used on account of the large variety of work with which it will deal.

43. *The lathe*

1. **Range of work.**—The lathe is a machine tool designed originally for turning cylindrical work. A standard sliding, surfacing, and screw-cutting lathe can be used :—

i. Without any special attachments, for :—

(*a*) Turning cylindrical work.
(*b*) Turning taper work.
(*c*) Boring cylindrical and taper work.
(*d*) Drilling, reaming, and tapping holes.
(*e*) Formed work that can be cut with a *formed* tool.
(*f*) Facing work that can be held on a face-plate or angle plate.

(*g*) Cutting screws internal and external of any desired form and pitch. For metric pitches a translating wheel containing 127 teeth is usually required.

ii. With the addition of milling cutters and an arbor, for :—

(*a*) Cutting keyways in small shafts.
(*b*) Cutting grooves in any work that can be fixed on the slide rest.
(*c*) Surfacing flat or formed work that can be fixed on the slide rest.

iii. With the addition of a taper turning attachment, for :—

Turning long taper or formed spindles.

iv. With the addition of a copying attachment, for :—

Formed work of irregular outline, *e.g.* a gunstock.

v. With the addition of a milling attachment and dividing head, for :—

(*a*) Cutting spur, helical, and angular gears, worms, and worm wheels.
(*b*) Cutting flutes in twisted drills, reamers, and taps.
(*c*) Making milling cutters of all types.

vi. With the addition of a grinding attachment, for :—

(*a*) Grinding cylindrical and taper work, inside, outside, or facing.
(*b*) Grinding all tools and milling cutters.

But operations (v) and (vi) are carried out more satisfactorily in a universal milling machine and a universal grinding machine respectively.

2. **Principle.**—The work is normally held between centres and rotated by means of a driver, D, on Pl. **24**, Fig. 13, fixed to the end of the work near the headstock, H. It may, however, be held on a face-plate or in a chuck, Pl. **27**, Figs. 1 and 2, the free end being supported by a centre, if necessary. Long work will also need steadies, or intermediate bearings, to support it in the middle of its length, S on Pl. **24**, Fig. 13. Modern lathes have hollow headstock spindles through which bars can be passed and held in a chuck while machining the ends. This also enables collet chucks to be used. (*See* para. 15, below.)

The tool is carried by a saddle, S on Pl. **25**, Fig. 3, which moves along *ways* or guiding surfaces, C and D, machined

upon the bed. The bed, B, is normally a massive cast iron box-shaped structure, having :—

i. A table formed at one end to carry the headstock.
ii. A depression, G, known as the gap, to allow work of large diameter to be carried upon the spindle, *see* Pl. **27**, Fig. 6.
iii. Carefully machined *ways* for the saddle and tailstock.

In England, lathes are described by the height of the centres above the bed, *e.g.* a 6-in. lathe. In an American catalogue, this would be described as a 12-in. lathe.

3. **Centres**.—The head centre revolves with the work and, therefore, any eccentricity in its position will affect the accuracy of the work. It should be tested by means of an indicator, or centre tester, T on Pl. **24**, Fig. 15, placed in the toolpost and brought up to the centre. Any eccentricity will be magnified by the long tail, which will sweep round in a circle if the centre is not true. Untrue or blunted centres should be ground true in the lathe where the centres belong, the grinding being done with a centre grinder.

The tail centre, or stationary one, should be precisely the same height as the axis of the spindle, and for parallel turning should be truly in line with it. This alignment can be roughly checked by sliding the tailstock towards the head. The centres should meet precisely at their points.

Centres are usually of 60° apex angle. Hollow or female centres are sometimes used, as shown on Pl. **24**, Fig. 16. Work must be prepared for turning between centres by drilling a small hole in each end, truly central and deep enough to clear the centre point. These holes are reamed out to fit the centre and bear upon its coned surface, as shown on Pl. **24**, Fig. 17. The two operations of drilling and reaming can be done simultaneously by means of a centre drill, Pl. **24**, Fig. 18.

4. **Headstock.**—The headstock, Pl. **25**, Fig. 1, contains a spindle, S, free to revolve in two bearings, B, placed sufficiently far apart to ensure true running. The nose, N, of the spindle is screwed outside to carry face-plates or chucks, and bored inside to carry a centre, which is usually standard Morse taper ; provision is also made for taking the end thrust of the centres.

In a simple lathe, the spindle carries a "stepped" pulley, having three or four steps, by means of which the spindle can be driven at different speeds by belt from another stepped pulley on a countershaft. The headstock usually also contains back gears, Pl. **25**, Fig. 2, by means of which slower speeds may be obtained. In this case the pulleys carried on the spindle must be free to revolve at a different speed. A

device, L, on Pl. **25**, Fig. 1, is provided for locking the pulley and the driven gear, G, together when the back gears are not in use. Plate **26**, Fig. 1, shows a modern lathe of simple type.

In some lathes the back gears can be thrown out of mesh by sliding the back shaft longitudinally, in others by moving the shaft away from the spindle by revolving headstock bearings. One or two trains of back gearing may be provided, giving, with the direct drives, a range of eight or twelve spindle speeds (with a four-step pulley).

More expensive modern lathes are often fitted with " all-geared " headstocks, in which all changes of spindle speed can be made with the gears, no stepped pulleys being used. The gears are changed by means of two or more handles, each having several positions. Changes must be made with the spindle stationary. Pl. **26**, Fig. 2, shows a lathe of this type.

In this case the headstock is usually provided either with fast and loose pulleys, or with a single pulley and a friction clutch, and can be driven direct from the main shafting without using a countershaft.

The headstock also normally carries the gears which operate the leadscrew and the splined shaft (*see* para. 6, below). For screw-cutting, the necessary train of gears to give the desired pitch are placed upon stub spindles and brought into mesh by revolving the arm (M on Pl. **28**, Fig. 1) which carries them. In more expensive lathes, the screw-cutting gears are often mounted permanently on shafts under the headstock, and the required gears for a large range of threads can be put into mesh by placing levers in different positions. A loose gear wheel will also be necessary to change the range of threads from English to metric measurements, or for any odd threads not included in the range.

For ordinary turning, a range of three or four speeds is frequently provided by means of permanent gears, and further speeds can be obtained by changing gear wheels.

5. **Saddle.**—The saddle or carriage is guided by shears or ways upon the bed, the form of which affects the accuracy and life of the lathe.

Pl. **25**, Fig. 3, shows a section through the saddle, S, and bed, B, of a well-designed lathe. Broad surfaces, A, carry the weight, while the surfaces C and D guide the saddle with more accuracy and much less friction than if only C and E existed. There should be contact at E. The saddle is held down by F and G. The leadscrew, L, is placed near to C and D to minimize cross stress, which produces inaccuracy and friction. The surfaces H and K provide a means for clamping the tailstock and steadies without interfering with C and D, so that the saddle can be very long and consequently firm.

PLATE 25.

TURNERS' WORK.

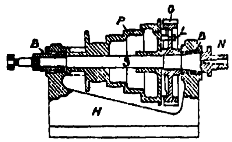


Fig. 1. LATHE HEADSTOCK

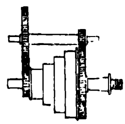


Fig 2. BACK GEARS

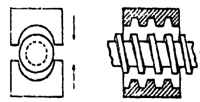


Fig 4. SPLIT NUT.

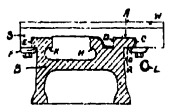
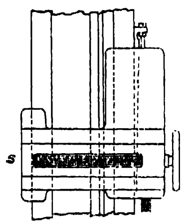


Fig 3. LATHE BED & SADDLE.



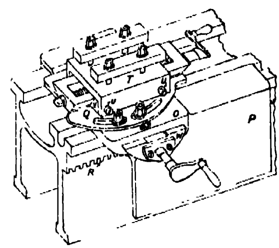


Fig 5. SADDLE WITH SLIDE REST

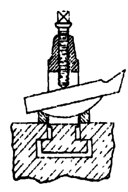


Fig 6 CUP TOOL HOLDER

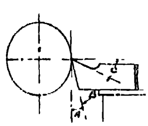


Fig 7 CORRECT HEIGHT

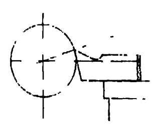


Fig 8 TOOL TOO HIGH

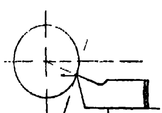


Fig. 9. TOOL TOO LOW

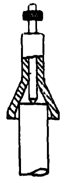
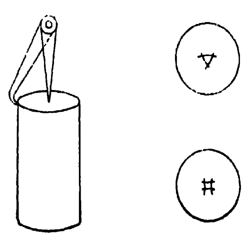


Fig. 10. BELL CENTRE-PUNCH



METHOD OF CENTRING ROUND-WORK.
Fig. 11.

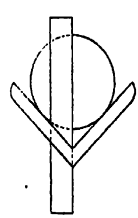


Fig. 12. CENTRE-HEAD SQUARE.

6. **Saddle traverses.**—Three methods of longitudinal traverse are generally available, viz. :—

i. By a leadscrew.
ii. By a rack and pinion.
iii. Top rest (by hand).

The leadscrew should only be used for screw-cutting. It should be very carefully cut; it soon loses its accuracy if continually used.

The rack is generally bolted to the bed, R on Pl. **25**, Figs. 3 and 5.

The drive is from the headstock through a splined shaft, on which is a pinion, free to slide, but keyed, and carried along the shaft by the saddle. Through gears this drives the pinion which engages with the rack. The leadscrew is put in operation by closing upon it a split nut, Pl. **25**, Fig. 4, carried under the saddle, while the rack pinion is controlled by a clutch in the apron.

7. **Slide rest.**—Upon the saddle, on ways, W on Pl. **25**, Fig. 5, at right angles to those on the bed, is carried the slide rest, O, and on this the toolpost, T. For surfacing work the cross traverse is put in operation by tightening a second clutch in the apron, P, of the saddle, which drives a cross feedscrew.

8. **Compound slide rest.**—In many lathes a further slide, Q on Pl. **25**, Fig. 5, operated by hand only, is carried by the first slide rest. This *compound slide rest* is capable of being swivelled by hand for taper cutting to any angle within its limits.

9. **Hand traverses and clamps.**—Every traverse is obtainable on a standard lathe by turning hand-wheels, or cranks, without using the power shaft clutches. The tool can thus be set to the desired cut, whether for turning or facing. When the tool is set, the traverse which is not in use may be clamped to ensure that the tool setting does not alter.

The saddle may generally be clamped by a lever on the apron, which tightens up one of the gibs engaging the projection, F or G on Pl. **25**, Fig. 3, on the bed. A similar clamp is usually provided to tighten one of the gibs of the slide rest. On Pl. **25**, Fig. 5, the top slide may be clamped by tightening the screws, U, with a screwdriver, thus forcing the gib, V, on to the shears.

10. **Toolposts.**—There are several types of toolpost in use; Pl. **25**, Fig. 5, shows the normal English type. It is of great importance that the tool should be set at the correct height. Pl. **25**, Fig. 7, shows a tool correctly set, its rake and clearance angles being true. Pl. **25**, Figs. 8 and 9, show

how these angles are completely altered if the tool is too high or too low. In the English type, the toolpost is normally made so that it will hold a standard tool too low, and it is necessary to insert suitable packing under the tool. Packing of precisely the correct thickness must be used; otherwise work would be delayed and spoilt, and tools would not last long.

In many American and other types of lathes a cupholder, Pl. **25**, Fig. 6, is fitted, by means of which the tool can be canted to bring the point to the desired height. This is not good practice, as it alters the angle of rake and the clearance.

11. **Cuts and traverses.**—The largest cut that should be taken in a standard modern lathe is one-fortieth of the height of centres, *e.g.* in an 8-inch lathe, 8/40 or $\frac{1}{5}$ inch.

The largest traverse, when taking this maximum cut, should not exceed $\frac{h}{160}$, *e.g.* for an 8-inch lathe, $\frac{1}{20}$ inch. Large traverses may be used for shallow cuts, but the area given by $\frac{h}{40} \times \frac{h}{160} = \frac{h^2}{6{,}400}$ must not be exceeded. Service lathes, especially those of mobile units, are normally of light construction, and are not intended for heavy cuts, portability having been studied in their design more than large output, *e.g.* in a light 8-inch lathe the cut should not exceed $\frac{1}{8}$ inch, and $\frac{1}{32}$ inch may be regarded as the normal traverse for this cut.

12. **Plain turning between centres.**—Accurate cylindrical turning can only be performed by following carefully a systematic sequence of operations and tests.

The lathe centres should first be checked and if necessary re-ground.

Both centres should be ground, in turn, when fixed in the mandrel pocket of the headstock, using a centre grinder on a toolpost. The tail centre should be ground first and then replaced in the tailstock (free from dirt and lightly oiled). When the revolving centre has been ground, the alignment should be checked as follows: Slide tailstock up so that tail centre is within $\frac{1}{16}$ in. of revolving centre, and clamp. With the aid of a piece of white paper observe if the centres are in line. If not, unclamp tailstock and make the necessary lateral adjustment with the offsetting screw on its base, clamp up and re-check.

Example.—To turn a spindle, about 12 *in. long,* $1\frac{3}{4}$ *in. diameter, from a* 2-*in. mild steel bar.*

(1) Cut off material by hand or machine saw to required length plus $\frac{1}{8}$ in.

(2) Mark the centre of each end with a bell punch (Pl. **25**, Fig. 10) or by a centre-head square (Pl. **25**, Fig. 12), if available, or by some geometrical method (Pl. **25**, Fig. 11), make light centre-punch mark and test again to ensure that it is truly central.

(3) Centre the spindle accurately, either by self-centring chuck (if the hollow mandrel on the lathe is big enough), or otherwise by 4-jaw independent chuck, and fix a steady on the projecting end. Then, using tailstock with a drill chuck carrying a centre or other drill, drill the ends as shown on Pl. **24**, Fig. 17.

In long lengths this can be done by a breast or other drill.

(4) Fill the centre holes with grease, fix a driver (Pl. **24**, Fig. 13) and place the bar in the lathe between centres. Screw up the tail centre until it grips the work firmly but without binding.

(5) Place a right-hand knife tool in the tool post and square the end down to the centre, removing only enough metal to be cutting everywhere.

(6) Put in a round-nosed roughing tool (cuts in either direction) traverse slide rest to the left, feed tool up and take a light cut for about half the length of the bar.

(7) Run saddle clear to tailstock, turn bar end for end, refix in centres and again traverse to left, keeping on the same cutting feed for remaining length of bar.

Now measure up accurately and make any necessary tailstock adjustments.

If a definite ridge appears near the centre of the bar where the two cuts join, the tailstock must be moved laterally by the offsetting screw; if the work is larger at the tailstock end than in the centre, the tailstock must be brought towards the cutting tool—and vice versa.

(8) Next use a straight-nosed roughing plain angle tool, turn down the shaft at about 50 ft. per minute to 1·13/16-in. diameter.

(9) Face the other end as in (5) to correct length.

(10) To finish off, use a right-hand finishing tool with a top rake of about 25° and take a cut equal to half the oversize measured above (*i.e.* $\frac{1}{64}$ in.). Run at half the original speed and use an ample supply of lubricant (a soapy compound is the best on mild steel).

By having a positive cut on the work a smooth and true highly polished surface should result.

SIMPLE BACK GEARED LATHE

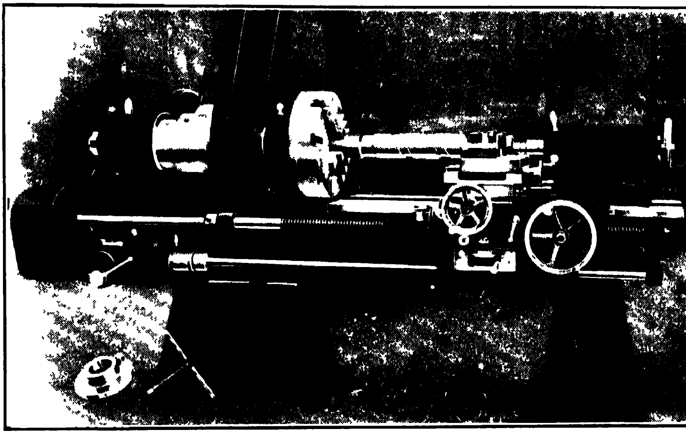


Fig. 1.

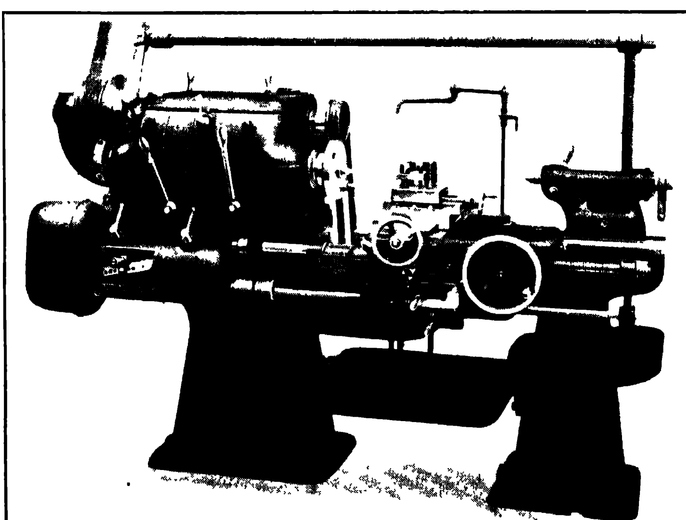


Fig 2.—Single pulley head and screw-cutting gear box.

[*Permission of Messrs. Dean, Smith & Grace, Keighley.*]

13. **Face-plate and chucks.**—Short work of comparatively large diameter is normally held in the lathe by means of a face-plate or a chuck screwed upon the nose of the spindle.

Pl. **27**, Fig. 1, shows a bearing, B, bolted to an angle plate, A, upon a face-plate, F. A balance weight, W, should be placed opposite any eccentric load upon the face-plate, otherwise the lathe will vibrate and the work will revolve in an irregular manner.

Pl. **27**, Fig. 2, shows a short cylinder held in a chuck, which is really a special face-plate with movable jaws upon its face, with which the work may be gripped.

Chucks are of two main types: (*a*) independent jaw chucks, (*b*) self-centring.

In the case of an independent jaw chuck, as actually shown on Pl. **27**, Fig. 2, each jaw is moved separately by a screw, whose head, S, can be seen. Thus, objects of irregular shape can be held, and any work which has already been turned can be brought truly central by careful adjustment.

In self-centring chucks, all the jaws move simultaneously and are generally controlled by a scroll inside the body of the chuck. They are convenient for holding short lengths of bar, if the part gripped is to be turned afterwards, or if the work is to be cut off when finished, leaving the rough stub in the chuck. They can seldom be relied upon to hold finished work truly.

A third type, known as a combination chuck, has both separate and simultaneous movements. A round bar can thus be gripped by means of the scroll, and any fine adjustment to bring the work central can be made by means of the independent screws. Similarly, work of irregular shape can be held when the scroll is released.

14. **Collets.**—For accurately centring round work of small diameter, a collet chuck is necessary (*see* Pl. **24**, Fig. 14). This is used in a hollow headstock spindle in conjunction with a special collet for each diameter of work to be handled. The collet is a split sleeve, bored internally to fit the work, and coned externally. By means of the collet chuck, which passes through the hollow spindle and grips the collet, the collet is drawn into the hollow spindle until the coned outer surface, fitting tightly into the spindle, causes the collet to close and grip the work and itself.

15. **Mandrels.**—Small work that has been drilled or bored can be held for turning upon a mandrel revolving between centres. Pl. **27**, Fig. 3, shows a plain drive fit mandrel, slightly tapered. Pl. **27**, Figs. 4 and 5, show other types, for coned work, &c.

PLATE 27.

TURNERS' WORK.

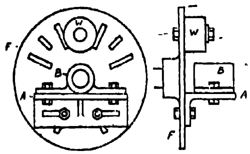


Fig. 1. FACE PLATE

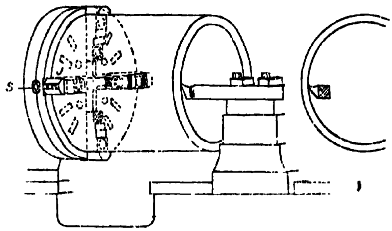


Fig. 2. BORING IN A CHUCK

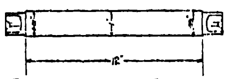


Fig 3 STANDARD 1" MANDREL

Fig. 4. CONE MANDREL

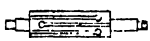


Fig 5 EXPANDING MANDREL

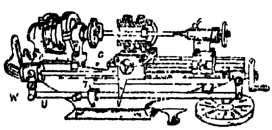


Fig. 6. BORING WITH PLAIN BAR

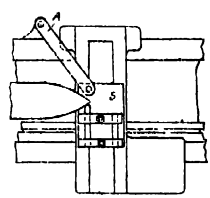


Fig 7 RADIUS TURNING

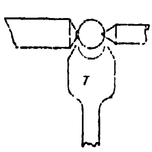


Fig 8 TURNING WITH FORMER TOOL

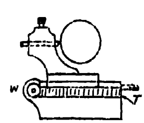


Fig 9 RADIUS TURNING

16. **Taper turning.**—Short steep tapers should be cut by setting over the compound slide rest at the required angle and traversing the tool by hand (*see* Pl. **25**, Fig. 5).

The setting over of either the slide rest or tailstock is difficult to do accurately. Therefore, after the roughing cut, the taper should be carefully measured by marking two points on the work a considerable distance apart, preferably near the ends of the work, and measuring the diameter carefully at these points. Any slight error in taper can then be remedied by a slight adjustment of the tailstock before applying the finishing cuts. A second readjustment may also be necessary.

It is absolutely essential for taper turning to have the cutting edge of the tool the exact height of the centres, or a true taper will not be obtained.

17. **Boring.**—Boring may be carried out in a lathe in the following ways:—

i. Work revolved on a face-plate or a chuck on the spindle, a boring tool being in the toolpost, Pl. **27**, Fig. 2. The height of the tool is of great importance, and the heel of the tool may require grinding away, as shown, to ensure clearance.

ii. Work bolted to the saddle, and bored by a cutter held in a bar revolving between centres, Pl. **27**, Fig. 6. The work must be packed up to the right height, rigidly fixed, and in line laterally with the axis of the cutter-bar. The bar must be about twice the length of the work; this limits the length of the work.

The cutter is normally carried in a hole in the bar, and clamped by a setscrew or wedge. The depth of cut is controlled entirely by the amount the cutter projects, the diameter of the bore produced being twice the distance from the centre line to the cutter point.

Example.—Boring a bearing.—Take the two halves as received from the foundry, file the rough off each end and clamp in a vice on a shaping or a milling machine. Set up with spirit level lengthwise and crosswise, and take a clean cut off both lips. Using a depth gauge for measuring, machine both halves to $\frac{1}{16}$ in. less than the diameter required to suit the shaft journal.

Then solder the two halves together.

After cooling, set up centrally in lathe in an independent 4-jaw chuck and machine projecting flange to size. Then reverse the bearing, clamping the machined flange in chuck

and set up truly as follows : Set a scribing-block pointer dead to height of lathe centre and pass it along the soldered seam on all sides. If true to the seam everywhere, the two halves of the bearing should be similar in size and the bearing truly central in the lathe.

To check this, revolve lathe mandrel through half a turn and use the scribing block again. The pointer should still be true to the soldered seam ; if not, adjust by dogs of chuck and check again.

When truly set up, secure the bearing in the chuck taking care not to throw it out of centre. Then face off and bore out to given tolerance. The machining of the outside diameter and clearance between flanges is left until last as this adds strength and helps to prevent the two halves of the bearing from parting before the boring operation is completed.

The bearing should be marked as machined before being unsweated.

18. **Drilling.**—Drilling may be done in several ways in a lathe, and the following three examples are given :—

i. The drill is revolved in the headstock, either held in a chuck or fitted into the tapered hole in the spindle, the work being fixed to the saddle.

ii. The drill is held still in the chuck or tapered hole in the tailstock spindle, or in V blocks upon the saddle, while the work is revolved by the headstock in a chuck or on the face-plate.

iii. Long cylindrical work can be mounted as for turning between centres, but with a twist drill in the tailstock instead of a centre. Care is required to ensure that the hole starts centrally. A small stiff drill, such as that shown on Pl. **24**, Fig. 18, should be run in a little way first, if a larger drill is to be used afterwards, to ensure a fair start. Holes so drilled are seldom truly central near the tailstock, unless a steady is used. A boring bar, used after the drill, will true up the hole.

Special drilling chucks are often used, similar to those normally fitted to sensitive drilling machines, Pl. **29**, Fig. 14. Reaming and tapping may also be carried out as in drilling machines. *See* Sec. **45**, paras. 16 and 18.

19. **Former turning.**—An article of curved or irregular outline can be turned, as shown on Pl. **27**, Fig. 8, by means of a former tool, T, whose edge is ground to the required outline. It is seldom worth the trouble of making the tool unless a large number of similar articles are to be produced.

If the edge of the tool is very broad, it is difficult to obtain sufficient rigidity in the work and tool to avoid vibration, which spoils the surface of the work.

20. **Radius turning.**—An outline in the form of a circular arc can be produced by means of a radius turning attachment, such as is shown on Pl. **27**, Fig. 9, traverse being obtained by a worm-feed, W, which rotates a turntable, T, fixed to the saddle.

Similar work of larger radius can be produced by controlling the cross movement of the slide rest, S on Pl. **27**, Fig. 7, by means of a pivoted arm, A.

21. **Taper-turning attachment.**—On lathes fitted with a taper-turning attachment external and internal tapers can be cut without offsetting the tailstock. This leaves a true bearing on the centres and saves time in not having to adjust the tail centre every time a taper job has to be done.

The attachment is fixed to the far side of the lathe and comprises a sliding block on a former bar which can be swivelled through a small angle by a fine-threaded adjusting screw. Scales graduated in degrees per ft. and inches per ft. are engraved on the base of the attachment, upon which the former bar swivels.

The compound slide rest has an extension which can be secured by a screw either to the saddle of the lathe for ordinary cylindrical turning or to the sliding block of the former bar for taper turning.

The hand slide is used to adjust the cut when the compound rest is locked to the sliding block and the work then proceeds as in ordinary traverse turning.

Very accurate tapers up to about 4 in. per ft. can be turned by this attachment.

22. **Facing.**—Work to be faced is usually held on a face-plate, or it may occasionally be held in a chuck. The facing is done by traversing the slide rest, and this traverse should be adjusted to suit the cut. The speed should be correct for the external circumference of the work.

In the case of very large work it may be advisable to increase the speed as the tool nears the centre. The tool must face the correct way, *i.e.* its rake must slope from both cutting edges, Pl. **24**, Fig. 12, and the side rake will be for a right-hand traverse.

23. **Screw cutting in the lathe.**—Screw threads are cut in a lathe by utilizing the leadscrew traverse for the saddle. Since the leadscrew drives by means of a split nut, the feed can be reliably and positively set any number of times.

The leadscrew has a definite number of threads to the inch. The pitch of the leadscrew, or distance from thread to thread, is generally $\frac{1}{2}$ in. for lathes with centres 8 in. high and upwards, $\frac{1}{4}$ in. for lathes with centres 6 in. high, and $\frac{1}{8}$ in. for small lathes with centres 3 or 4 in. high.

Thus, in a 6-in. lathe with a $\frac{1}{4}$-in. pitch leadscrew, if the screw revolves at the same rate as the work the saddle will move $\frac{1}{4}$ in. for every spindle revolution, and the tool will trace a $\frac{1}{4}$-in. pitch thread on the work. To cut 8 threads to the inch, or $\frac{1}{8}$-in. pitch, the leadscrew must turn at half the rate of the work, and so on for other pitches.

If a 24-tooth pinion is placed upon the keyed extension at the back of the lathe spindle, A on Pl. **28**, Fig. 1, a 48-tooth pinion upon the end of the leadscrew, C, and an *idle* pinion, B, of any convenient size, such as a 36-tooth, upon a stub shaft on the arm, M, then the ratio

$$R = \frac{\text{revs. of screw}}{\text{revs. of work}} = \frac{24}{36} \times \frac{36}{48} = \frac{1}{2}$$

As the leading screw has 4 threads per inch, this ratio will give the required thread, 8 to the inch.

For pitches that cannot be obtained by the ratios of any two available gears, a fourth pinion must be introduced, as shown on Pl. **28**, Fig. 2. The spindle or driving pinion, A, may be offset by means of a spacing collar, W, so that it engages with D. D and B are keyed so that they must revolve together, and B drives C.

The ratio $R = \frac{A}{D} \times \frac{B}{C}$. Thus, to obtain 9 threads to the inch on the work, the following gears could be used :—

$$\frac{4}{9} = R = \frac{A}{D} \times \frac{B}{C} = \frac{24}{36} \times \frac{32}{48}.$$

If a left-hand thread is to be cut, the leadscrew must revolve in the opposite direction and the screw is cut from left to right. This can be attained by using the reverse tumbler gear, or, as shown on Pl. **28**, Fig. 3, by placing an *idle* pinion, E, so that it meshes with B, and swinging the arms so that B is thrown out of mesh with C, while E engages C.

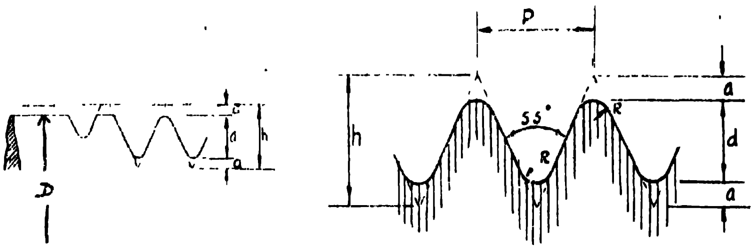
The ratio is unaltered: $R = \frac{A}{D} \times \frac{B}{E} \times \frac{E}{C} = \frac{A}{D} \times \frac{B}{C}$, but the direction of motion of the leadscrew is now reversed.

24. Forms of screw thread.—For manufacturing reasons it is essential to have *standard dimensions and forms* of screw threads.

The following are the principal forms of thread used in Great Britain :—

i. British Standard Whitworth Vee Thread.
ii. British Association Vee Thread.
iii. Cycle Engineers' Institute Vee Thread.
iv. Square Thread.
v. Acme Thread.
vi. Buttress Thread.

i. *British Standard Whitworth Vee Thread.*—The apex angle of this thread is 55° and the core diameter $C = D - 2d$, where D is the overall diameter and d the actual depth of the thread. Other particulars are given in Fig. 1.



Theoretical depth $h = 0{\cdot}96P$ (P = pitch).
Actual depth $d = 0{\cdot}64P$.

Rounding at crest and root $= a = \frac{h}{6} = 0{\cdot}16P$.

Radius at crest and root $= 0{\cdot}1373P$.

FIG. 1.—*British Standard Whitworth Thread.*

The following British Standard Threads are of Whitworth form :—

(*a*) *British Standard Whitworth (B.S.W.) Thread.* (B.S.S.92).—This is the form of thread most generally used in British Engineering work. Particulars are given in Appendix I.

(*b*) *British Standard Fine (B.S.F.) Thread.* (B.S.S.84).—The pitch of the B.S.F. threads is finer than that of the B.S.W. threads, *e.g.* a ½-in. bolt has 12 threads per in. when screwed B.S.W. and 16 threads per in. when screwed B.S.F. Corresponding values for 1-in. bolts are 8 and 10. (*See* Appendix I.) The greater number of threads to the inch results in a stronger bolt, enables finer adjustments to be made and reduces the tendency to become unscrewed by vibration. B.S.F. threads are used in high-class machine work, in mathematical and scientific instruments, motor vehicles and lock nuts for machine tools.

(*c*) *British Standard Pipe* (*B.S.P.*) *Thread.* (B.S.S.21).—Used for iron and steel pipes (commonly known as "gas" threads). This thread has a relatively fine pitch to reduce the depth of cutting; ½-in., ⅝-in., and ¾-in. pipes have 14 threads to the inch and pipes of 1 in. diameter and upwards 11 threads to the inch. (*See* Appendix I.)

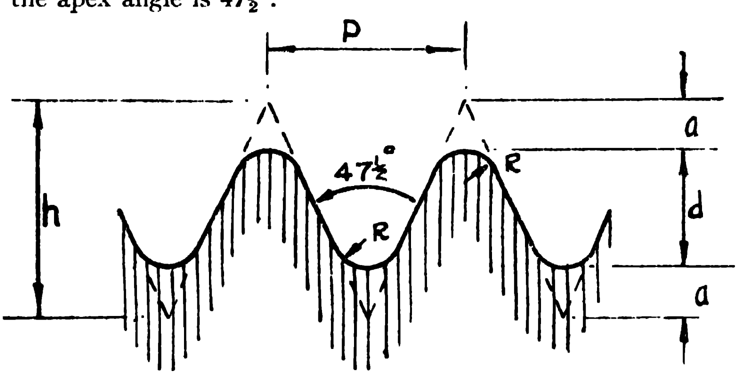
(*d*) *British Standard Brass* (*B.S.B.*) *Thread.*—There is no B.S. Specification for this thread, but it is largely used for thin brass and copper tubes, *e.g.* the barrels of optical instruments and electric lampholders. The number of threads to the inch is 26 for all diameters of tube. The service equipment for cutting this thread is known as "Tools, screw cutting for brass and copper tubes."

(*e*) *British Standard Thread for Copper Pipes and Tubes.* (B.S.S.61).—For domestic purposes. There are three series, for low, medium, and high pressure pipes. For particulars the specification must be referred to.

(*f*) *British Standard Thread for Steel Conduit for Electric Wiring.* (B.S.S.31).—Sixteen threads to the inch for sizes from ⅝-in. to 1¼-in. diameter.

It may be noted that *iron and steel* pipes are specified by their *inside* diameter, except in the case of steel conduit for electric wiring: the latter, and brass, copper and compo pipes by their *outside* diameter.

ii. *British Association* (*B.A. Thread*). (B.S.S.93).—This thread is similar in appearance to the Whitworth thread, but the apex angle is 47½°.

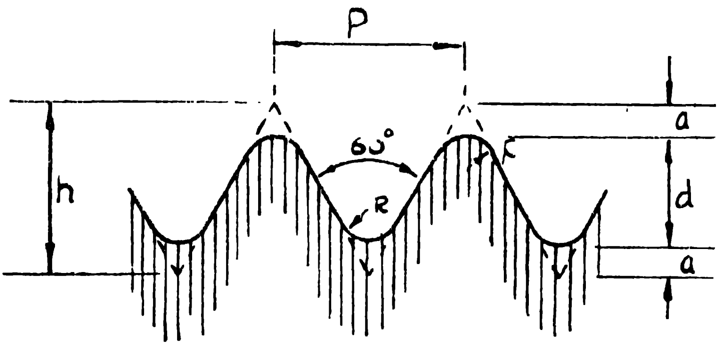


Theoretical depth $h = 1{\cdot}136$P.
Actual depth $d = 0{\cdot}6$P.
Rounding at crest and root $a = 0{\cdot}27$P.
Radius at crest and root $= 0{\cdot}182$P.

FIG. 2.—*British Association Thread.*

It is used in sizes up to ¼-in. diameter, mainly for instrument work. B.S.W. threads in the smaller sizes are considerably coarser in pitch than B.A. threads, consequently the latter hold better and are stronger for the same outside diameter owing to the larger cross section under the threads. B.A. threads are graded by numbers from 0 to 15, even numbered threads being most commonly used in the service, *e.g.* a 2 B.A. screw has a full diameter of about 4·7 m.m. and a pitch of 0·81 m.m. (approximately 31·3 threads to the inch). (*See* Appendix I.)

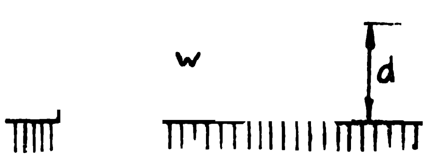
iii. *Cycle Engineers' Institute Standard Thread.*—There is no B.S. Specification for this thread, particulars of which are shown in Fig. 3. and in Appendix I. Note that the apex angle is 60°.



Theoretical depth $h = 0{\cdot}866P$. Actual depth $d = 0{\cdot}5327P$.
Rounding at crest and root $a = 0{\cdot}1666P$. Radius at crest and root $= 0{\cdot}1666P$.

FIG. 3.—*Cycle Engineers' Institute Standard Thread.*

iv. *Square Thread.*—This form of thread is used to transmit motion, *e.g.* on the feed mechanism of machines, vice screws, screw jacks, etc. It is not so strong as the Whitworth thread, but it offers less frictional resistance to motion. As the name implies, the height of the teeth in a square thread is equal to the width. (Fig. 4.)

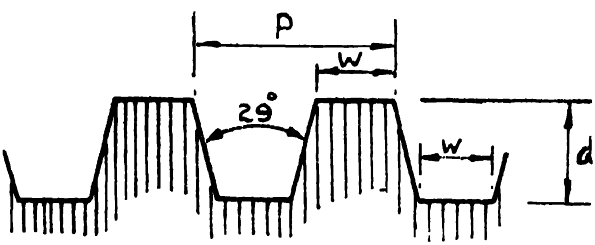


d = depth = 0·5P. w = width = 0·5P.

FIG. 4.—*Square Thread.*

There is no standard, but the pitch is often taken as twice that of a standard Whitworth thread of the same diameter. (*See* para. 28 for multiple start threads.)

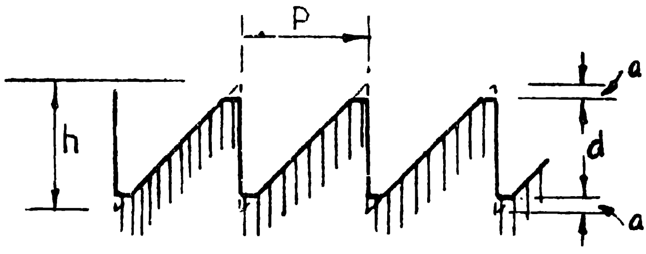
v. *Acme Thread.*—Used instead of a square thread for lead screws. It is easier to engage with a split nut than a square thread. The apex angle is 29°.



$d = 0{\cdot}5P + 0{\cdot}01$. $w = 0{\cdot}3707P$.

FIG. 5.—*Acme Thread.*

vi. *Buttress Thread.*—Used to take pressure one way only, *e.g.* in the breech mechanism of guns. Apex angle = 45°.



Theoretical depth $h = P$.
Actual depth $d = 0{\cdot}75P$.
Angles at crest and root truncated to depth $a - 0{\cdot}125d$.

FIG. 6.—*Buttress Thread.*

For a given length of nut, the shearing strength of a buttress thread is twice as great as that of a square thread.

vi. *Other forms of Thread.*—Other forms of thread may still be found in use for special purposes, but are not likely to be met with in the service.

vii. *Foreign Threads.*—The two principal foreign forms of thread are :—

(*a*) *The Sellers Thread,* which is the U.S.A. standard thread. The apex angle is 60° and the actual depth = 0·65P. The angles at crest and root are truncated to form flats $\frac{1}{8}$th of the pitch in width. The number of threads to the inch is approximately the same as for B.S.W. threads of the same diameter. (*See* Appendix I.)

(*b*) *The International Standard* (*Metric*) *Thread.*—This thread is used largely on the Continent. It is similar to the Sellers thread except that the groove at the bottom is rounded. A metric thread on a 12-mm. diameter bolt has a pitch of 1·75 mm., *i.e.* about 14$\frac{1}{2}$ threads to the inch, and a 24-mm. bolt has about 8$\frac{1}{2}$ threads to the inch. Compare with B.S.W. $\frac{1}{2}$-in. and 1-in. bolts which have 12 and 8 threads to the inch respectively. (*See* Appendix I.)

25. **Form of threading tools for V threads.**—The point of the tool must conform to the shape of the standard thread which is to be cut. The apex angle must be correct for a V thread, or the sides properly squared for a square thread. The point must be rounded off correctly for the bottom of a British thread.

The rounding off of the tops of threads is generally done separately, after the full depth has been cut to the outline shown on Pl. **28**, Fig. 5.

Since the tool cuts with its point and both sides, it is important that the clearance, or relieving, angle shall be carried right round.

It is difficult to apply the desirable angle of rake to both sides ; therefore, none is given in small tools, but in very large ones the top may be cupped or ground slightly hollow, as shown by the dotted line on Pl. **28**, Fig. 5. A small angle of rake may be given at the point, but this should not be excessive. The tool should be set so that the top is truly at right angles to the direction of the thread, which is never perpendicular.

A thread gauge, G on Pl. **28**, Fig. 6, should be used to check the form of the tool and thread while being cut, and to ensure that the sides of the thread are equally inclined.

26. **Cutting V threads.**—When lathe, tool, and work have been properly set, with the carrier, or other means of driving the work, rigid enough to ensure that it will not slip relatively to the spindle, the tool can be brought up to the work and set for a fine cut, but clear of the end. The lathe should be run

PLATE 28.

SCREW CUTTING.

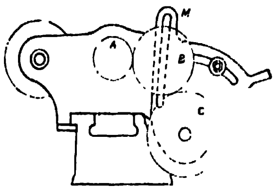


Fig. 1. SCREW-CUTTING GEARS

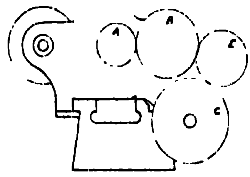


Fig 3 LEFT-HAND THREAD.

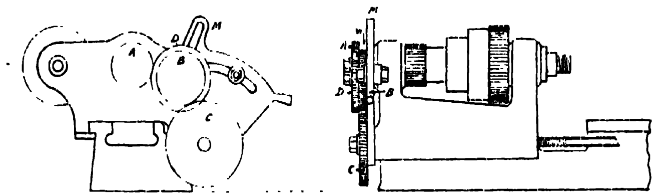


Fig 2 COMPOUND GEARS

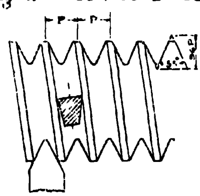


Fig. 5. THREAD FULL DEPTH

Fig 6. THREAD GAUGE

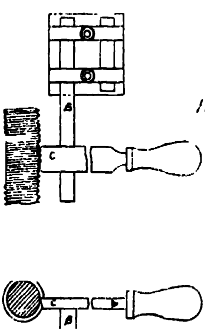


Fig 4 CHASING THREADS

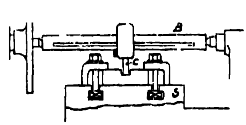


Fig 8. FLY-CUTTING SLOTS

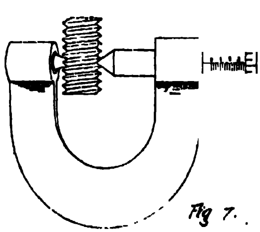


Fig 7. THREAD CALLIPER.

at a slow-cutting speed, such as 10 ft. per minute. The split-nut in the saddle is then closed upon the leadscrew, and the tool traces a fine spiral line upon the work. The operator must be ready with one hand upon the nut lever and the other upon the slide-rest wheel. Both feed and cut must be taken off simultaneously when the thread is long enough. This operation must be quickly performed if the thread is to be cut close up to a shoulder, otherwise the tool may dig into the shoulder and twist the work in the carrier, or the tool may be broken. The saddle is then run back for another cut.

The slide-rest feedscrew wheel of most lathes is graduated in thousandths of an inch, so that it is easy to set the tool back to the same position as before, and then advance it a little so as to cut a little deeper. If not graduated, a chalk mark may be made upon the top of the wheel before starting. The wheel may then be re-set by bringing the chalk mark to the top, and then a little farther, so as to give a suitable increase of cut, such as 0·02 for a 1-in. screw, 8 threads to an inch. The chalk mark may now be rubbed off, and another made on what is now the top of the wheel.

Before the leadscrew is engaged again, it is important to ensure that the new cut will follow exactly in the track of the first.

If the thread to be cut is a multiple of that on the leadscrew, no error can be made, and the nut can be closed at once. If, however, an *odd thread* is being cut, such as the 9 threads to the inch calculated in para. 23, the threads on the work and leadscrew will only coincide once in every inch, or once in 4 turns of the leadscrew. If the nut is dropped into one of the three other turns, it will cut an entirely new spiral and spoil the work.

If marks are made on the work and leadscrew the first time they are engaged, and these marks are always brought on top before the nut is dropped in, the work and screw will register every time. A more accurate method is to chalk the tooth nearest the top (or nearest horizontally, as convenient) on the pinions on the spindle and leadscrew.

After a few cuts, the thread begins to assume the desired form. The depth should be ascertained by measuring either the diameter of the core or the distance from the bottom to the opposite tops of the threads with thread callipers, as shown on Pl. **28**, Fig. 7.

When the core is about 0·01 oversize, fine cuts should be taken, giving the smallest feed that will ensure a cut, measuring after each run, and stopping when the core is 0·001 oversize. These fine cuts will improve the surface and be more accurate than the roughing cuts.

27. **Chasing V threads.**—The thread may now be finished and left rounded at the top by using a chaser, C on Pl. **28**, Fig. 4, which is merely a forming tool, very carefully made to the correct shape for the threads.

The lathe may be speeded up to about 40 ft. a minute or more, and the chaser engaged on the first thread, with a gentle firm pressure, and allowed to run along the work, guided by a hand-turning rest. A good hand-turning rest may be improvised by placing a bar of steel, B, of suitable length, in the toolpost, and fixing it parallel with the work.

The first cuts will only round the tops. As soon as the chaser begins to cut on the sides of the threads, the latter should be carefully measured, in several different places, at the tops. If a thread is large in any place a very light cut may be taken again there only, taking care that the chaser does not run on to places that are already down to size. This can best be done by marking the large place and running the chaser over the whole length, but with only the heel of the tool touching when no cutting is to be done, and allowing the edge to bite when desired by raising the handle a little. If the chaser is correctly formed, the tops and bottoms will come to size together.

28. **Cutting square threads.**—Square threads are cut in a lathe in the same manner as V threads, using a cutting tool of suitable shape.

The surface of a square thread is normal to the axial force against which the screw acts and there is no oblique or bursting pressure on the nut as with the V thread. There is also less friction and less wear with this form of thread, but they are more expensive to cut.

They are used chiefly to transmit motion.

Multiple threads.—The durability of a screw thread depends upon the area of its bearing surface, *i.e.* upon the depth of the thread. But the deeper the thread is cut, the smaller is the cylinder diameter below the thread, and for this reason multiple threads are used when a large lead giving a quick traverse is desired.

Pitch and lead of screw threads.—These terms are frequently misunderstood. The *pitch* of a thread is the distance from the centre of one thread to the centre of the next. The *lead* of a screw is the distance the nut travels in one revolution. The pitch and lead are clearly the same with a single thread, but with a double thread the lead is twice the pitch, and so on.

Cutting multiple threads.—When cutting multiple threads it is necessary that the first (driver) wheel on the lathe mandrel should contain a number of teeth divisible by the number of

threads in the lead, *e.g.* a treble thread could be cut with a driver having 30, 45 or 60 teeth.

The number of teeth in the gear wheel on the leadscrew will depend upon the relative values of the lead of the screw to be cut and the pitch of the leadscrew of the lathe.

Example.—To cut a double square thread.—To cut a double thread, say, with $\frac{1}{2}$-in. lead, assuming the pitch of leadscrew of the lathe to be $\frac{1}{2}$ in.

Select two wheels with the same number of teeth, say, 40, mount one (the driver) on the lathe mandrel and the other on the leadscrew. Any convenient intermediate wheel may be used on the stud to gear up.

For a double thread, the width of the cutting tool must be equal to one-quarter the lead of the screw to be cut, *i.e.* $\frac{1}{8}$ in. plus 0·002 inch tolerance for a $\frac{1}{2}$-in. lead.

Cut the first thread to its full depth of $\frac{1}{8}$ in. There will be two complete turns per inch of length.

Having completed the first thread, chalk two diametrically opposite teeth on the driver, and the two adjacent teeth on the intermediate wheel between which one of the marked teeth on the driver engages. Then drop the swing frame, give the mandrel exactly half a turn and gear up again with the two marked teeth on the intermediate wheel engaging the other diametrically opposite marked tooth on the driver.

The second thread may then be started, and care must be taken that it is cut to the same depth as the first. The second thread will be diametrically opposite to the first.

It will be noted that the pitch of this double thread is $\frac{1}{4}$ in., the lead of the screw is $\frac{1}{2}$ in. and the cylinder diameter below the threads is $\frac{1}{4}$ in. greater than it would be on a single-threaded screw with the same lead.

29. **Keyway cutting and surfacing.**—Keyways and similar grooves in flat surfaces may be cut in a lathe by means of a fly-cutter, C on Pl. **28**, Fig. 8, which is carried by a boring-bar, B, *see* also Pl. **27**, Fig. 6.

The work is fixed to the slide rest, S, traversed across the lathe bed, instead of along it as when boring, and fed against the cutting movement of the cutter. The tool or cutter should be made precisely to the form of the keyway if it is to be cut at one traverse. There is no objection, however, to making several successive traverses if the groove to be cut is very deep or wide.

The width of the tool is only limited by the strength of the cutter-bar. Therefore, wide surfaces can be so machined at one pass, provided sufficient rigidity can be attained. This is the same operation as milling.

30. **Milling attachment.**—Gear cutting is most easily carried out by means of a lathe milling attachment, Pl. **29**, Fig. 1. The blank or disc, B, is held on an arbor between the lathe centres, and located by means of a dividing plate fixed to the headstock, as shown on Pl. **31**, Figs. 5 and 6.

For small gears, the cutter, C, may be carried with its axis horizontal, and be passed over the top of the blank. For cutting large gears, this necessitates a very high pillar for the attachment. More rigidity can be attained, therefore, by revolving the cutter about a vertical or inclined axis. Its plane must pass through the line of lathe centres, Pl. **29**, Fig. 2. *See* Sec. **44**, para. 7.

For cutting worms, the headstock spindle must revolve slowly to give the feed against the cutter. The cutter must be carried by the saddle, traversed by the leadscrew, precisely as for cutting screw threads with a plain tool, but all movements are slow. The headstock spindle should be driven through a worm gear, and the ratio of movement of the leadscrew obtained in the ordinary way through gears on the screw-cutting arms, Pl. **28**, Fig. 1.

The plane of the cutter must be tilted to the angle of the thread, *see* Pl. **28**, Fig. 5.

Helical and angular gears are merely worms of very steep pitch. Wormwheel cutting requires a special attachment, *see* Sec. **46**, para. 11.

Flutes in twisted drills are merely worms of a special section and of very steep pitch. Those in straight flute drills, reamers, and taps are parallel to the axis, and correspond to spur-gear cutting.

The flutes should be milled to full depth in blanks of rather larger diameter than the finished product, because (*a*) the milling produces a burred edge which must be subsequently removed, and (*b*) the blanks must be milled soft and hardened afterwards, and are almost certain to warp. This burring and warping is corrected in grinding down to the required diameter.

Milling cutters with circumferential teeth are mounted and cut as described for spur gears, or helical gears in the case of spiral mills. They must be cut from slightly oversized blanks while soft, and then hardened and ground (*see* above).

Blanks for face cutters or end mills are similarly mounted, but the cutter is traversed by means of the slide rest cross-feed. The milling attachment should be set to revolve its spindle in a vertical axis, and the cutter brought approximately to the height of the lathe centres.

NOTE.—Milling cutters cannot undercut. Therefore, if any rake is to be given to the teeth of a milling cutter blank, the operating cutter must be tilted or put out of centre to produce a surface which, though radial to the cutter, is raked on the blank, Pl. **29**, Fig. 3.

For details of milling cutters, speeds, &c., *see* Sec. **46**.

44. *Planing and shaping machines*

1. **Range of work.**—Planing and shaping machines are designed to machine surfaces which can be produced by a succession of straight-line cuts.

The work that can be done by them includes plain surfacing, keyway slotting, bevelling, and the development of irregular or curved surfaces of such a nature that every stroke of the tool can be in a straight line, such as spur gears.

2. **Planers.**—A planer, Pl. **30**, Fig. 5, is a machine in which the work is moved longitudinally to produce the cut, and is carried by a travelling carriage, C, which runs on ways upon the surface of a bed, B. The traverse is supplied by a transverse movement of the tool, which is carried by a saddle, S, upon a cross rail, R, over the work.

The tools employed are generally similar to lathe tools, but are forged so that the cutting edge is vertically under the back of the tool against the tool-box. Power is supplied, generally through pulleys and a train of gears, to a pinion upon the side of the bed, which engages with a rack fixed under the carriage. The transmission includes a reversing gear, such as a double fast and loose pulley system, which is thrown over at each end of a stroke by adjustable stops, A, upon the carriage.

The tool cuts in one direction only, and the speed of the stroke in this direction must be a suitable cutting speed for the tool. In the reverse direction there is no such limiting factor, and there is no load due to cutting ; hence the power transmitted by the pulleys is sufficient to return the carriage at a greater speed. The transmission is normally geared to reverse at about twice the speed permissible on the cutting stroke. The working belt should leave its fast pulley before the reversing one is thrown on ; this avoids conflict between the belts and excessive slipping. The wear on the belts is heavy in any case.

The saddle is usually traversed by a leadscrew, L, which is turned a little during each reverse stroke of the bed by a ratchet gear, G, the stroke of which is adjustable to give the desired traverse. The saddle carries a swing frame, F, upon which is the tool-box, T.

The detail of a typical planer head construction is shown on Pl. **30**, Fig. 6.

The tool-box may be tilted to a limited extent to adjust the direction of the tool point. It carries pivoted in it an apron, E, sometimes called a *clapper*, which can swing out on the return stroke to free the tool from the work. Upon the apron is the toolpost, T.

The tool-box should be so tilted that when the apron lifts,

the tool is not only drawn up from the surface of the work, but also swings away from the cut.

3. **Shapers.**—Shapers are straight-line cutting machines in which the tool is moved to produce the cut, carried by a ram, R on Pl. **30**, Fig. 7, which is driven by a rack and pinion in the case of large machines, with reversing gear like that of a planer, giving a suitable forward speed for the cut and a quick return. In small machines the ram is moved by some device, such as the vibrating link and crank shown on Pl. **30**, **Fig. 8**, which supplies the desired quick return. The great unsupported length of the ram deprives the machine of the rigidity and accuracy of the planer.

The ram-head, H on Pl. **30**, Fig. **7**, carries a swing frame, slider, tool-box with apron, and toolpost as described for a planer.

The table, T, is often of box form, generally capable of being elevated and tilted to any desired angle, and cut with wards on the top and all three sides, to which vices can be fixed. It is provided with screw adjustment for height, and in American type machines is carried upon a traversing saddle. In English type machines the table is stationary, and the ram is carried in a traversing saddle.

4. **Slotters.**—A slotting machine is a shaper, whose ram has a vertical movement, the working stroke being made downwards towards a table, which is generally provided with feed traverse in either direction, and also feed rotation, Pl. **30**, Fig. 9. It is particularly adapted to cutting keyways in the bosses of pulleys, and holes and outlines of irregular shapes, rectangular, circular, &c.

The design of the machine ensures great rigidity.

5. **Holding work.**—Large work is generally bolted down to the surface of the table. Smaller rectangular work is normally held in a machine vice, Pl. **29**, Fig. 9. Round work, such as shafts to be key-slotted, is held between centres, or clamped down to a ward in the table, Pl. **31**, Fig. 2, or to V blocks.

6. **Special work.**—Circular arc outlines may be cut in a planer or shaper by fitting an attachment, as shown on Pl. **31**, Fig. 3, which is carried in the toolpost. The inserted tool point, I, sweeps out a circular arc when the head, H, is turned by means of a hand-operated worm gear, W.

Spiral slots may be shaped in shafts by fitting a device which turns the shaft between the centres with a reciprocal motion corresponding to the strokes of the ram.

7. **Shaping spur gears.**—Gears may be shaped by mounting the blank on a mandrel held between centres, and

locating the blank by means of a dividing head, Pl. **31**, Fig. 6. *See* also para. 9.

The tool should be of the right form to produce the teeth, and should be fed into the blank to the required depth. Then the blank is rotated through the correct angle, and another tooth is shaped. In cutting a new gear to replace a broken one, the precise form of the teeth must be very carefully reproduced.

8. **Shaping bevel gears.**—Bevel gears can only be produced accurately by means of a special shaping machine.

9. **Dividing head.**—For gear cutting, accurate rotary location of the blank is essential. This is secured by means of an indexing head.

Pl. **31**, Fig. 4, shows a plain indexing head for holding work between centres on the table of a planer, shaper, or milling machine. The headstock spindle carries a dividing plate, D, keyed to it, containing regularly-spaced holes into which an indexing plunger, P, can be placed in succession.

Pl. **31**, Fig. 5, shows an indexing attachment to fit directly upon the mandrel holding a blank, working upon the same principle.

Pl. **31**, Fig. 6, shows a worm dividing head, by means of which very fine adjustments can be made, and a large variety of divisions can be obtained from any one plate; *e.g.* if 40 turns of the worm crank, C, produce one of the worm wheel, W, and there are 18 holes in the circle equally spaced round the plate, D, a movement of the spring plunger, P, from one hole to the next causes only 1/720 of a revolution of the spindle.

To cut a 36-tooth gear, each movement must be 20/720 revolution = 20 spaces, or one revolution of C and two spaces farther.

For cutting spirals, the worm is driven by coupling it to the traversing gear, so that it turns at the correct rate, as for screw cutting. *See* Sec. **43**, para. 23.

45. *Drilling, reaming and tapping by machine*

1. **Methods.**—Holes may be drilled, reamed, and tapped as follows:—

i. By hand, using a standard and ratchet brace or a breast or a portable power drill for drilling, and a key for reaming and tapping.

ii. In a lathe, provided that the work can be held in a chuck, or bolted to the saddle in a suitable position.

iii. In a drilling machine.

Drilling by hand is explained in Sec. **38**, which should be studied before this section, to which it forms an introduction.

2. **Drilling, &c. in the lathe.**—Three methods of drilling in a lathe are given in Sec. **43**, para. 18. Reaming may be done similarly, but the reamer is often allowed to *float, i.e.* it is not guided after it has entered the hole. This may be provided for by placing the reamer in the mouth of the hole, with a key upon its squared end, and bringing up the tail centre to a centre hole drilled in the head of the reamer. The key may be held by hand, or prevented from turning by means of a hand rest, which may be extemporized, as shown on Pl. **28**, Fig. 4.

3. **Drilling machines.**—In these the drill is normally carried in a vertical revolving spindle, while the work rests on a horizontal table. There are two principal types :—

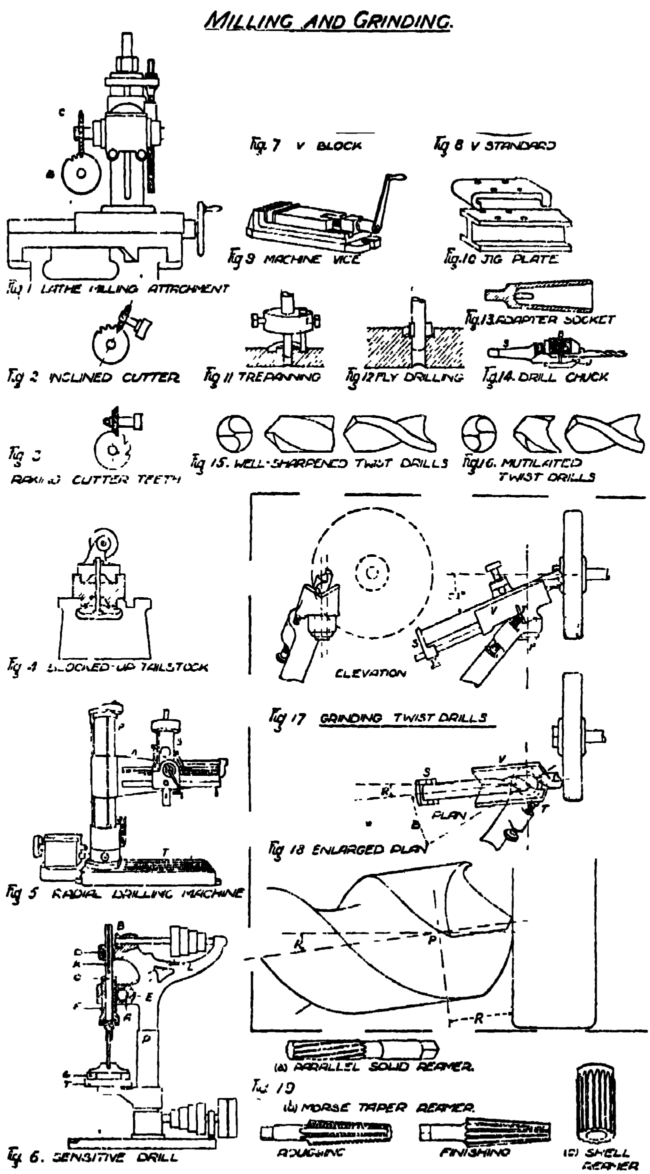
i. *Pillar drilling machines*, in which the spindle is carried by a fixed arm, and can move vertically to feed the drill into the work, but has no lateral traverse. The work is moved on the table to bring the correct point under the drill. (*See* Pl. **29**, Fig. 6.) In a *sensitive drill* the drill is fed in by hand, being controlled by a lever giving a quick, light control, which allows the pressure essential on the drill point to be felt by the operator. Larger machines may have an automatic feed or a slow hand feed by a wheel, but, in general, pillar drills are of the sensitive type, and of moderate size. The table can be adjusted vertically to suit the size of the work.

ii. *Radial drilling machines*, in which the spindle is carried by a saddle, which slides along a radial arm. The arm can be rotated about a central pillar ; the drill can thus be traversed laterally in all directions, and centred over any point on the work, which remains stationary on the table. The drill spindle can be fed down through the saddle by hand or automatic feed, and in some cases the arm can also be raised and lowered to suit the size of the work ; in others the table can be raised and lowered. Radial drills are suitable for working on large, heavy jobs which cannot conveniently be moved about on the table, and are expensive machines built for heavy work. (*See* Pl. **29**, Fig. **5**.)

Multiple spindle and horizontal drilling machines are used for special work in production workshops, but are not likely to be met with in the service.

4. **Spindles.**—The spindle, C on Pl. **29**, Fig. 6, to carry the drill is usually solid, and passes through a driving quill, D. It can slide vertically through this quill, but is forced to turn with it by a key and keyway, K.

PLATE 29.


MILLING AND GRINDING.
Fig 1 LATHE MILLING ATTACHMENT
Fig 2 INCLINED CUTTER
Fig 3 RAKING CUTTER TEETH
Fig 4 BLOCKED-UP TAILSTOCK
Fig 5 RADIAL DRILLING MACHINE
Fig 6. SENSITIVE DRILL
Fig. 7 V BLOCK
Fig 8 V STANDARD
Fig 9 MACHINE VICE
Fig.10 JIG PLATE
Fig 11 TREPANNING
Fig 12 FLY DRILLING
Fig.13 ADAPTER SOCKET
Fig.14. DRILL CHUCK
Fig 15. WELL-SHARPENED TWIST DRILLS
Fig 16. MUTILATED TWIST DRILLS
ELEVATION
Fig 17 GRINDING TWIST DRILLS
PLAN
Fig 18 ENLARGED PLAN
(a) PARALLEL SOLID REAMER.
Fig 19
(b) MORSE TAPER REAMER.
ROUGHING
FINISHING
(c) SHELL REAMER

This driving quill is carried in bearings in the arm or saddle, and receives the power through the belt and pulleys, or, in larger machines, through bevel gearing, B, as shown.

The spindle carries upon it another quill, the feed quill, F, which does not rotate, and in modern machines has ball-bearing thrust washers to take the weight of the spindle when running idle, and the thrust of the feed when drilling. The feed quill has usually a rack cut upon it, with which a pinion, E, engages, to raise or lower the quill and spindle. This pinion is usually revolved by a hand lever, L, and in large machines it has also a power drive. The lower end of the spindle has a Morse taper hole into which the shanks of drills fit tightly.

5. **Drive.**—The spindle is sometimes driven by an endless belt, passing over suitable guide pulleys, from a horizontal shaft carried on the frame. This shaft carries *cone* or stepped pulleys, and so does the countershaft from which the power is taken. Thus various speeds may be obtained. *See* Pl. **25**, Fig. 1. Large machines may also contain back gears, as in a lathe, for obtaining large torque at low speeds for drilling large holes.

6. **Drilling speeds.**—The revolutions of the spindle are limited by the speed of the outer corners of the lips of the drill, which should not normally exceed 25 ft. per minute when cutting mild steel, 20 ft. when cutting cast iron, and 50 ft. when cutting soft brass. This corresponds to 96 revolutions a minute for a 1-in. drill cutting mild steel, 76 cutting cast iron, and 192 cutting brass. Other sizes of drill may be speeded in inverse proportion to their diameter, *e.g.* $\frac{1}{4}$-in. drill cutting mild steel, $4 \times 96 = 384$ r.p.m.

Special high-speed drills may be run much faster, at 50, 100, or even 300 per cent. more than the above figures, according to their quality.

7. **Feed.**—The rate of feed is limited by the work the square point of the drill can do without overheating. A 1-in. carbon-steel drill is usually fed at 1/90 in. per revolution, and others at $\frac{\sqrt{d}}{90}$, *e.g.* a $\frac{1}{4}$-in. drill at $\frac{\sqrt{\frac{1}{4}}}{90} = \frac{\frac{1}{2}}{90}$ $= \frac{1}{180}$ in. per revolution.

8. **Pilot drilling.**—The power actually required at the drill point is approximately proportional to the amount of metal removed per minute, if the hole is drilled in one operation. The power required may be considerably reduced by drilling a small hole first, and then putting through the larger drill. The time taken for a large hole on a given machine is

thus much reduced. More accuracy is also obtained, since the small drill can be better centred, and the small hole guides the point of the larger drill.

9. **Holding work.**—Work must be so held that the drill passing through it will not damage the table of the machine. This may be best arranged for rectangular work by placing it upon rectangular machined blocks of cast iron, which keep the work square, G on Pl. **29**, Fig. 6.

Work of other shape may need special holding devices to ensure square holes, such as V blocks for round work, Pl. **29**, Fig. 7, V standards for long work, Pl. **29**, Fig. 8, and a machine vice for irregular-shaped work, Pl. **29**, Fig. 9.

10. **Drilling jig.**—When several articles are to be made to a standard design, a jig plate should be used to ensure similarity, Pl. **29**, Fig. 10.

The plate may be of cast iron or mild steel, but if many similar articles are to be made, the holes should be bushed with hard steel, otherwise they would wear rapidly in soft plates.

The jig plate must be accurately located by some means, such as contact with definite surfaces or shoulders. If the actual position of the holes is not important, but only their relative positions, pins of the same diameter as the holes may be placed in the first two holes drilled as soon as the drill is withdrawn. This will ensure location for the remainder of the holes.

11. **Types of drill.**—The three normal types of drill are described in Sec. **38**, para. 3.

Twist drills are used exclusively for machine drilling.

12. **Trepanning and boring with a fly-cutter.**—Large shallow holes may be bored in small machines by trepanning with a fly-cutter, Pl. **29**, Fig. 11. Deeper holes will need all the metal to be removed, Pl. **29**, Fig. 12. A hole is first drilled the size of the cutter-bar, which should fit it closely, but without binding.

13. **Spot-facing.**—A fly-cutter may be used similarly for spot-facing the surfaces of a casting round a hole, to give a proper flat bearing for a nut, the bar being fitted, if necessary, with a bush to fit the hole.

14. **Drill chucks and sockets.**—A drill too small in diameter to fit the Morse taper hole in the spindle may be held by means of adapters or sockets, Pl. **29**, Fig. 13. Drills smaller than $\frac{3}{8}$ in. are generally made with a parallel shank, and are held in a drill chuck, Pl. **29**, Fig. 14. This type of drill chuck has three jaws, which are closed on the drill by turning the body, B, by hand. The tail or shank, S, fits the taper of the hole in the spindle of the machine.

15. Sharpening drills.—

i. Drills must be kept sharp in every respect. On Pl. **29**, Fig. 15, and Pl. **29A**, Fig. 1, it will be seen that the point of a twist drill is a straight line square to the axis, and is the intersecting line of two surfaces. The lips slope back at 59° to the axis. Each lip is a cutting edge, with a clearance angle of 12° to 15° to ensure that only the edge touches the bottom of the hole, and an angle of rake to make it cut freely. The edge should be straight from the point to the outside surface of the drill stem. Both edges must be of the same length and at the same angle, or the drill will not cut accurately to size.

ii. Pl. **29**, Fig. 16, shows a mutilated twist drill, which has the following faults :—

(*a*) The point is rounded through feeding too fast.
(*b*) The corners of the lips are rounded through speeding too high.
(*c*) The lips are unequal, the result of unskilled grinding.
(*d*) The relieving or clearance angle has been destroyed.

iii. The effect of these faults will be :—

(*a*) It will require great force to drive forward the blunt point.
(*b*) The rounded lips will make the drill jam in the hole.
(*c*) The hole will not be straight, round, or true to size, and one lip will do most of the work.
(*d*) The drill will glaze its hole instead of cutting it, since the edge cannot enter the metal.

Pl. **29A**, Fig. 2, shows what happens when the point of a drill is central but the cutting edges ground to different angles, and Fig. 3 shows the result of grinding the cutting edges to equal cone angles but different lengths.

iv. Pl. **29**, Figs. 17 and 18, show a drill-sharpening attachment for a tool grinder, to enable the correct form, as shown on Pl. **29A**, Fig. 1, to be obtained.

(*a*) The drill is held in a trough, V, which holds it at the correct angle of 59° to the surface of the wheel.
(*b*) A stop, S, holds the drill up against the wheel, and ensures equality of the lips and correct centring of the point, provided both drill lips are placed vertical when grinding.
(*c*) The relieving or clearance angle is obtained by swivelling the trough, V, about the pivot, P. The heel of the lip can be ground down, but the stop, T, prevents any swivelling the other way, and so prevents any rounding off of the edge, which has a relieving angle equal to R, adjustable by setting the stop, T. The angle increases farther away from the edge, to give better clearance, by the angle B, through which V is swung while grinding.

PLATE 29A.

TWIST DRILL

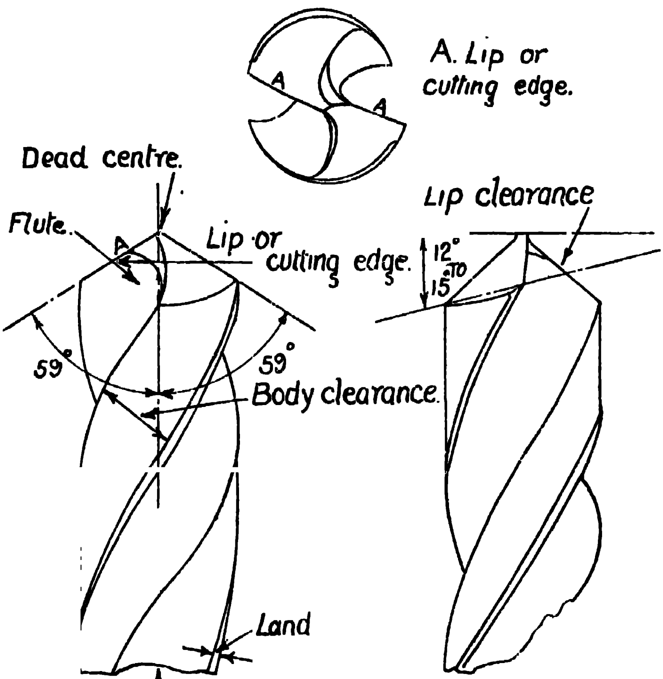


Fig. 1

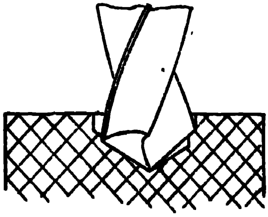


Fig. 2

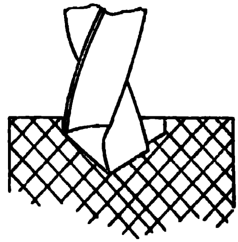


Fig. 3.

PLATE 30.

MACHINE TOOLS

Fig 1

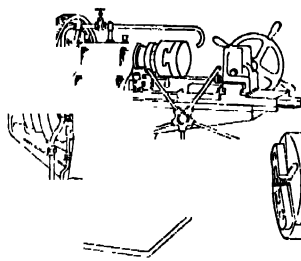


Fig 2 SCREWING MACHINE

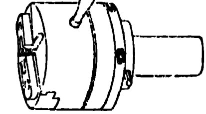


Fig 3 BOX DIES

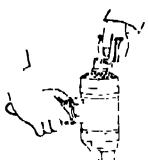


Fig 4 PORTABLE ELECTRIC DRILL

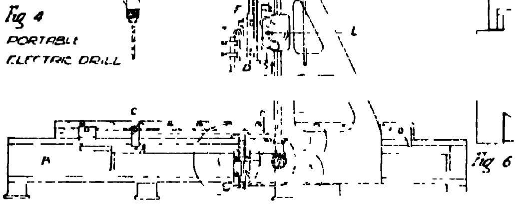


Fig 5 PLANING MACHINE

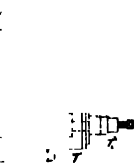


Fig 6 PLANER HEAD

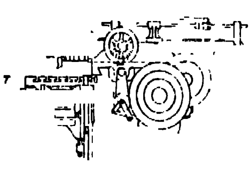


Fig 7 SHAPING MACHINE

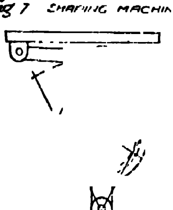


Fig 8. VIERA

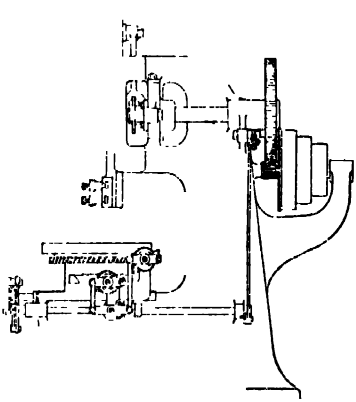


Fig 9. SLOTTING MACHINE

16. Reamers.—Reamers are used like drills, but not to remove a large amount of metal. They are merely used to straighten and true holes; therefore, a drill must be used first till the hole is 1/64 in. undersize.

A reamer should be run slowly, with plenty of oil, and fed rapidly by hand. It should preferably be passed straight through a hole, and not be drawn out backwards. Blind holes should be reamed, and the reamer should be withdrawn quickly while still revolving.

Machine reamers are generally given a little clearance to their teeth, and, therefore, must not be revolved backwards, or chips will jam behind the teeth and score the hole.

Pl. **29**, Fig. 19, shows (*a*) a parallel solid reamer, (*b*) a tapered reamer for trueing Morse taper holes, and (*c*) a large shell reamer to fit on to a mandrel.

There are also various forms of adjustable reamers, with inserted teeth, which can be forced out a little by screwing in a central coned spindle. They are unlikely to be available in a service unit.

On no account must a reamer be sharpened by grinding or whetting the outside surface. Its accuracy would be entirely spoilt by such a procedure. Reamers are better blunt than too sharp. They should, when necessary, be re-sharpened, as shown on Pl. **32**, Fig. 10, by a properly qualified tool grinder.

17. Broaches and broaching.—The process known as "broaching," or the machining of surfaces by a tool having a number of successive cutting teeth of gradually increasing size, is now being extensively adopted in production work. The process is used for castellating nuts, spanner jaws, cutting keyways and squaring holes, and for many other jobs which would otherwise have to be done by drilling and slotting.

Even for round holes, the broach is now superseding the reamer, as the latter has a tendency to score a hole. In broaching, no scoring can take place and a smooth and true surface is obtained.

Broaching is done by two methods, the "pull" and the "push." The "push" type broach was originally known as a "drift." The "pull" type which is now most commonly used, is longer than the push type, and is machine driven.

18. Tapping.—Machine taps should be fitted to a spring tapping attachment, and if possible the tap should be passed straight through only. Blind holes are better tapped by hand.

It is important that the tap should be free to follow its threads. Therefore, either the tap should be free to descend or the work to rise on the tap. Pl. **30**, Fig. 1, shows nuts being tapped on a sensitive drilling machine, held in a box jig, which

allows them to run up the tap, while preventing them from turning.

19. **Screwing.**—Bolts and pipes are screwed normally in special screwing machines, but may also be screwed in a lathe, or a large drilling machine by means of dies.

i. Pl. **30**, Fig. 2, shows a screwing machine for pipe-work, &c. The pipe or rod is held in a V-jawed vice, and the dies in a head, which is capable of revolving.

ii. In lathe work on bars, it is more usual to revolve the bar, passed through the hollow spindle and held in a chuck. The dies are then stationary, and are allowed to advance.

iii. Modern types of box dies, Pl. **30**, Fig. **3**, as fitted to turret and automatic lathes, are arranged to extend a spring as they run on to the work, and a trigger is provided, which releases the dies when a stop is reached. The dies then open automatically, and the spring pulls them off the work.

20. **Portable drilling machines.**—Portable pneumatic and electric drilling machines are useful for the erection of bridges and other large structures, or for any work which is too large to bring to a fixed machine.

Pl. **30**, Fig. 4, illustrates an electric drill. A small motor drives the drilling spindle through reducing gearing. Arms, A, are provided for holding the machine. A back-centre with screw extension should be provided for use under a standard, as shown on Pl. **18**, Fig. 13.

46. *Milling machines*

1. **Principle.**—Milling cutters operate upon the principle of the fly-cutter, Pl. **28**, Fig. 8. A simple milling cutter is a cylinder having, as shown on Pl. **31**, Fig. 7, upon its circumference a number of teeth, or cutting edges, each one formed according to the principles of cutting tools outlined in Sec. **42**, para. 2.

End-cutters have their teeth, or edges, upon one end of the cylinder.

In operation, the cutter is made to revolve at a uniform speed. This motion produces the cutting action, so that the cutting speed is the product of the revolutions per minute and the circumference of the cutter in feet; $S = \frac{\pi d N}{12}$ feet per minute.

Each edge of a circumferentially toothed cutter is in action during only a small portion of a revolution, and then completes the revolution freely, while the other teeth in succession are

operating upon the work. Thus, any one edge, after operating for a short period only, enjoys a period of rest, during which the heat generated passes away, partly into the air or any cooling fluid which may be provided and partly into the body of the cutter. Thus, when the tooth comes into action again, it will be comparatively cool.

During the next period of action, the amount of heat generated by cutting may exceed the amount conducted away, but no harm will be done, provided the excess of heat is insufficient to raise the temperature of the cutting edges to such an extent as will draw their temper. Obviously, therefore, in otherwise similar conditions, a circumferential milling cutter can cut the same metal faster than a turning or planing tool, whose edge is in action for long periods. On the other hand, the edges of an end-milling cutter, Pl. **31**, Fig. 8, are not only in action continuously, or nearly so, but they follow one another before the heat developed in the work can be much dissipated. The metal worked upon becomes very hot, and assists little in conducting away heat from the cutting edge of the tool. Therefore, in end-milling, the metals cannot be cut so fast as by turning or planing.

Small end-mills are merely many-toothed drills, *see* Sec. **45**. Large end-mills are sometimes used for machining flat surfaces, but so long as they cut on the whole face or end of the cylinder, they must be run at drilling speeds.

2. **Machines.**—Milling machines are usually similar to a planer or shaper, in which a milling cutter is substituted for a plain tool.

In nearly all milling operations the *work*, *i.e.* the object which is being worked upon, is fed slowly and continuously towards the cutter, and in a direction opposite to that of the cutting movement of the teeth, Pl. **31**, Fig. 9.

Each tooth in succession removes a chip of metal ; teeth of the same length remove equal amounts of metal, provided they are equally spaced round the cutter and the feed is uniform.

The pressure of the cutting edge resists the action of the feed, and thus takes up any backlash in the feed mechanism ; thus a truly uniform rate of feed is ensured. If the feed were in the same direction as the movement of the teeth, the work would occasionally be drawn forward by a tooth to the extent of the backlash, the feed would be unsteady, and some teeth would cut more metal than others. The heavy load thus put upon the cutter and machine might stop the machine or cause breakage.

3. **Cutters.**—In any milling operation, the feed and the rotation of the cutter combine to produce a surface whose

contour in cross-section is a precise reverse of that of the teeth on the cutter.

i. A plain cylindrical cutter will, therefore, leave a plane surface if the feed is in a straight line.

ii. Cutters may also be designed to cut moulded surfaces of any simple contour. They are known as formed cutters. Some types are shown on Pl. **31**, Fig. 10.

iii. Cutters are carried in the milling machine upon arbors, Pl. **31**, Fig. 11. Two or more may be placed upon the same arbor if desired; the operation of such assemblies of cutters is known as gang milling. Complicated outlines can thus be produced from a few simple and standard cutters.

The cutters are held tightly between a shoulder on the arbor and a nut, collars being used to space the cutters as desired, or to fill up any space between the shoulder or nut and a cutter. These collars help to stiffen the arbor.

For heavy milling work, the cutters are keyed to the arbor to ensure that they cannot slip. It is essential that the hole in every cutter shall be truly central, and shall fit the arbor well; otherwise, all the work would be done by a few teeth, and any eccentric cutters would bite deeper than they should.

4. **Teeth.**—The teeth of milling cutters are generally made with little or no rake, both for convenience in manufacture and to keep ample strength in the teeth.

The relieving angle is produced during manufacture by *backing-off*, a grinding operation shown on Pl. **32**, Fig. 11. The tooth is located with the edge a little beyond the vertical to ensure a relieving angle, A on Pl. **31**, Fig. 12, of about 5°.

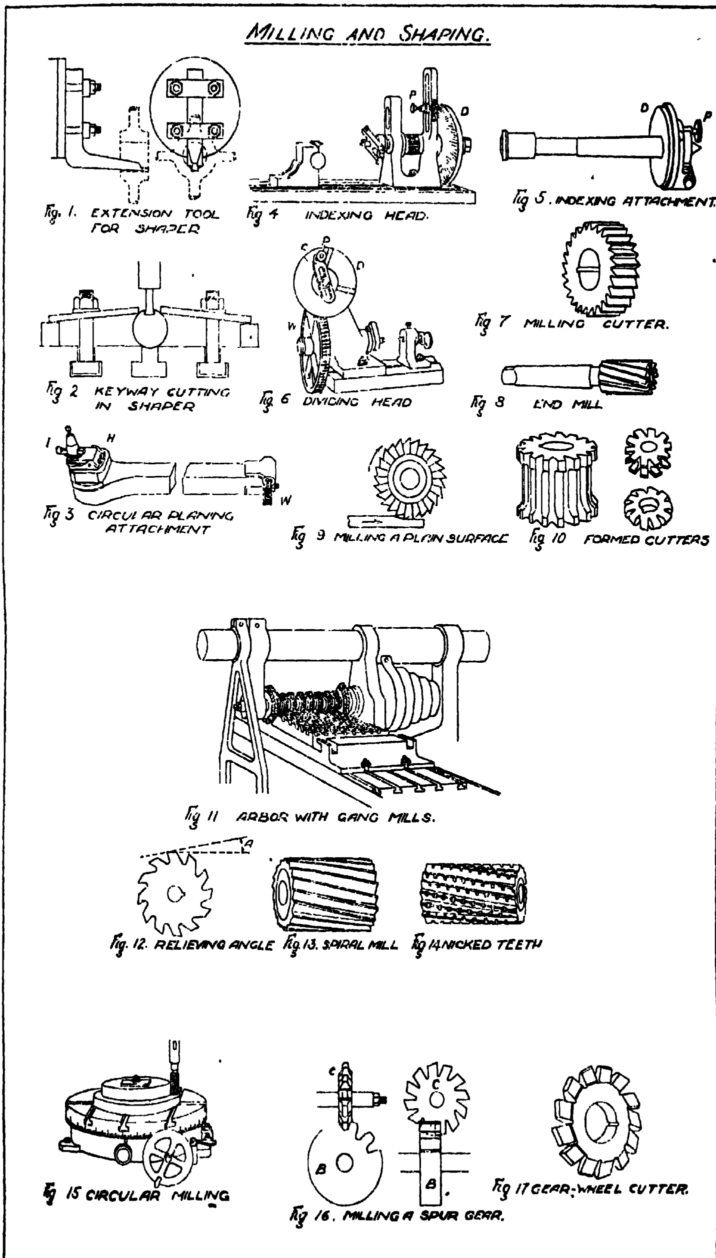
The teeth are re-sharpened by grinding on the cutting face only, so that their profile may be left unaltered. They must not be ground anywhere else. Between each tooth and the next is a deep groove, to provide space for the chips as they curl off the work.

To ensure that a tooth bites, the depth of cut must be considerable. Therefore, a few large teeth, with ample chip clearance between them, cut better than small teeth, whose clearance is generally insufficient to hold the chip.

The normal number of teeth in a cutter of diameter D inches is $\sqrt{288D}$ for cast iron and mild steel and $\sqrt{128D}$ for brass.

Cutters of considerable length are often made with spiral teeth, as shown on Pl. **31**, Fig. 13. This causes smoother cutting, since the chips come off in long spiral rolls, and the action is more continuous. The spiral chips are, however, a

PLATE 31.


MILLING AND SHAPING.
Fig. 1. EXTENSION TOOL FOR SHAPER
Fig 4 INDEXING HEAD.
Fig 5. INDEXING ATTACHMENT.
Fig 7 MILLING CUTTER.
Fig 2 KEYWAY CUTTING IN SHAPER
Fig 6 DIVIDING HEAD
Fig 8 END MILL
Fig 3 CIRCULAR PLANING ATTACHMENT
Fig 9 MILLING A PLAIN SURFACE
Fig 10 FORMED CUTTERS
Fig 11 ARBOR WITH GANG MILLS.
Fig. 12. RELIEVING ANGLE
Fig 13. SPIRAL MILL
Fig 14 NICKED TEETH
Fig 15 CIRCULAR MILLING
Fig 16. MILLING A SPUR GEAR.
Fig 17 GEAR-WHEEL CUTTER.

disadvantage, because they tend to pin in between the teeth and interfere with the work. To avoid this, the teeth are sometimes interrupted or nicked, as shown on Pl. **31**, Fig. 14. By this device the chips are broken up.

Large cutters may also be made with inserted teeth, generally of high-speed steel, set in a body of a tougher carbon steel.

The teeth of deep cutters, such as parting cutters or circular saws, should be wider than the body of the cutter; compare the lathe parting tool shown on Pl. **24**, Fig. 9. This can be ensured by grinding the flat side of the cutter body slightly concave.

5. **Cutting speeds and feeds.**—The normal cutting speeds are given in Table **K**, page 146.

The rate of feed is usually expressed in revolutions of the cutter per inch of feed, normally about 40 for a 3-in. diameter cutter working on mild steel. The actual rate of feed varies from ½ in. to 3 in. per minute, and depends upon the width of the cut and the capacity of the machine.

If a cutter, properly set and sharpened, is not cutting steadily the cutting speed should be reduced, and the feed slightly increased if the machine can provide the necessary increase of power, and the work and arbor can stand the stress.

6. **Circular milling.**—Circular surfaces may be produced by a milling process as easily as in an ordinary lathe.

In this case the work is carried between centres, in a chuck, or upon a face-plate, and is slowly revolved as the milling cutter removes the metal. Pl. **29**, Fig. 1, shows a milling attachment for a lathe. Pl. **31**, Fig. 16, shows a small profiling mill operating upon work fixed to the revolving table of a vertical milling machine.

7. **Profile milling.**—Irregularly shaped forgings can be machined true on their exterior in a vertical milling machine, a controlling object being used as a pattern. For example, cams may be conveniently machined to proper shape and dimensions by using a template cam fixed on the machine table as a guide.

8. **Milling in the lathe.**—A lathe can be used as a plain milling machine, without any attachments, by carrying the cutter on an arbor between centres, as shown on Pl. **28**, Fig. 8, the work being fixed to the slide rest, and the cross-traverse feed used. *See* Sec. **43**, para. 30.

9. **Milling spur gears.**—Spur gears are normally milled. The blank or disc, B on Pl. **31**, Fig. 16, held on an arbor between centres, is located by a dividing head. The cutter, C,

is formed to the precise shape of tooth required, and carefully adjusted to cut to the correct depth into the blank. The cutter is then fed into the work, and moves in a direction parallel with the tooth until it has passed right through the blank. To avoid spoiling the work, it is advisable to make the first cut a little shallow, and then make a second pass after measuring the depth of tooth formed, making the necessary fine adjustment of the table to ensure the correct depth. The dividing head is then revolved through the necessary angle, *e.g.* 10° for a 36-tooth gear, and the next groove cut. No subsequent adjustment or second passes should be necessary for this or for any other tooth.

10. **Milling worms and spiral gears.**—Worms and spiral gears are cut similarly to screw threads by traversing the blank and simultaneously revolving it. The operation is, therefore, easily performed in a lathe (*see* Sec. **43**, para. 30).

11. **Milling a worm-wheel.**—A worm-wheel may be generated on a milling machine if a positive power feed is available for rotating the work.

The work can be done equally well in a lathe, fitted with an attachment by means of which the blank can be revolved positively through gearing and at a definite ratio to the revolutions of the lathe spindle. Pl. **32**, Fig. 1, illustrates the principle. The blank, B, is geared to a master worm-wheel, M. The worm milling cutter, or hob, H, is mounted on the same arbor as a master worm, W. H is an exact copy of W, except that portions of the thread of the worm are cut away to form milling teeth.

When the arbor is revolved, W causes M to revolve, and B also revolves, driven by the gearing from M. H, therefore, reproduces the form of the teeth of M on the periphery of B. The arm, R, carrying the gears connecting M and B, must be capable of movement, so that B can be fed in towards H by turning the slide-rest traversing screw, S.

A worm so produced will not be very accurate, because all irregularities in the teeth of H will be reproduced in B. This can be avoided and greater accuracy obtained by slowly traversing the saddle carrying M and B. Thus every time a tooth on B comes round it will be machined by a different part of H, and any irregularities, whether of H, W, or M, will be evenly distributed.

The unavoidable irregularities in the gearing between M and B may be similarly evenly adjusted by using a master worm-wheel with a different number of teeth to B, and gearing M and B in the same ratio. Thus, if B is to have 40 teeth, M may have 36, if the gearing is selected so that B makes one revolution to 40 of the arbor.

12. **Machine sawing.**—All toothed metal saws, whether reciprocating or rotating, may be regarded as milling cutters. The same cutting speeds may be applied, but the feed should be slow, because the teeth of saws are generally fine, and cannot accommodate large chips between them. Some device is often used to clear the teeth of large saws, such as a star pinion at right angles to and running in mesh with the teeth.

47. *Grinding machinery*

1. **General principle.**—Every grinding machine can be considered as a milling machine in which an abrasive wheel takes the place of a milling cutter.

An abrasive wheel may be considered as a milling cutter in which, instead of a few steel cutting edges, many thousands of small cutting edges have been substituted, each consisting of the point of an exceedingly hard crystal, each crystal being embedded in a matrix, formed into the shape of the wheel.

In consequence of the small size of the cutting points, and, therefore, the small cut made by each one, very high cutting speeds are possible ; the normal speed of the circumference of the wheel is 5,000 ft. per minute for external cylindrical work, and 4,000 ft. for surfacing. The extreme hardness of the cutting points enables work to be carried out upon material which no steel tool could cut.

Grinding is the only method of machining hardened steel. Steel tools, spindles, bearings, &c., must necessarily be hardened, and in the process of hardening they usually warp a little. Therefore, such tools, &c., after being forged, machined approximately to shape and size, hardened, and tempered as desired, are finally ground to their finished shape and size.

The fineness of the cut taken by each crystal point is such that no appreciable pressure need be exerted by the point on the work. In consequence, the most delicate work can be ground without appreciable deformation or inaccuracy, due to whip or springing of the work or machine.

The accuracy obtainable is, therefore, of a much higher order than that of a machine using steel cutting tools.

Although each point makes a very small cut, the large number of the points and the high speed at which they cut enables metal to be removed very rapidly. In consequence, if the wheel is pressed into the work, a large amount of heat is generated ; also if the wheel is made to work upon one portion of the work for a long period, that portion becomes very hot. The consequences of this are :—

- i. The temper of the work may be spoilt by local overheating.
- ii. Local heating produces local expansion, and, therefore, deformation of the work, which destroys its accuracy.

To avoid any such local overheating, work requiring great accuracy, such as a long spindle or a large surface, is normally ground down only about one-thousandth of an inch at each pass of the wheel, measured on the diameter. Whether the wheel or work traverses is immaterial as far as the operation of grinding is concerned, provided the wheel never remains cutting at any one spot for any appreciable time.

2. **Cylindrical grinding.**—Pl. **32**, Fig. 2, shows a universal grinding machine, which, with its centre heads, H and J, constitutes a lathe specially designed for the use of an abrasive wheel as the cutting tool. An ordinary lathe can be used for this purpose but it is not so suitable (*see* para. 5).

3. **Traverse and Feed.**—The Table **T**, carrying the headstock and tailstock, can be traversed both longitudinally and transversely. Change of direction of longitudinal movement is carried out automatically at the end of each pass and the transverse movement necessary for feeding the work to the wheel can be effected by hand or automatically as desired. The grinding wheel has vertical movement only (which is required for surface grinding). While it is being traversed to and fro longitudinally the work is held between centres and revolved so that the work and the wheel turn in opposite directions at the point of contact. A copious supply of coolant must be used to prevent overheating and consequent distortion of the work.

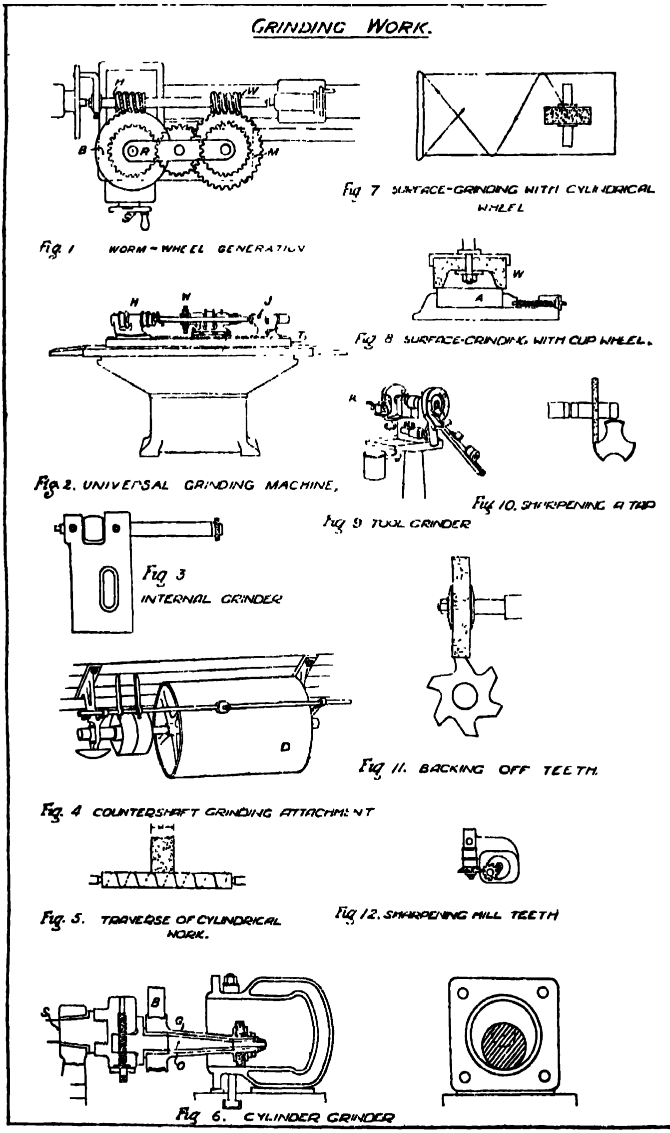
Excellent results as regards finish are obtained by letting the wheel run over the work several times without cross-feeding.

The work is usually allowed to overrun the wheel a little at the end of each pass to complete a cut. If the wheel is allowed to overlap the work by more than about one-third of its width, however, external cylindrical work becomes slightly tapered at the ends and internal work becomes bell-mouthed. The work must never be allowed to run on clear of the wheel or the edges of the latter will be broken off.

4. **Wheel spindle speed.**—In some modern machines the wheel spindle always revolves at the same speed for any one standard size of wheel. The rim speed is usually set at 6,000 ft. per minute for a new wheel for external work. The wheel can be used till it is only two-thirds of its original diameter, giving 4,000 ft. per minute. The accepted average of 5,000 ft. is thus obtained, and any small corrections are made in the speed of revolution of the work, which must, in any case, be altered for almost every new piece of work.

5. **Grinding in the lathe.**—The slides and spindle bearings of a grinding machine are specially protected from the grit and abrasive dust produced by the wearing down of

PLATE 32.


GRINDING WORK.
Fig 1 WORM-WHEEL GENERATION
Fig 2. UNIVERSAL GRINDING MACHINE,
Fig 3 INTERNAL GRINDER
Fig. 4 COUNTERSHAFT GRINDING ATTACHMENT
Fig. 5. TRAVERSE OF CYLINDRICAL WORK.
Fig 6. CYLINDER GRINDER
Fig 7 SURFACE-GRINDING WITH CYLINDRICAL WHEEL
Fig 8 SURFACE-GRINDING WITH CUP WHEEL.
Fig 9 TOOL GRINDER
Fig 10. SHARPENING A TAP
Fig 11. BACKING OFF TEETH.
Fig 12. SHARPENING MILL TEETH

the wheel. Since an ordinary lathe is not so protected, it should be used sparingly for grinding work. In the absence of a special machine, however, cylindrical work can be ground in a lathe, if a grinding attachment, as shown on Pl. **32**, Fig. 3, is placed in the toolpost, or the milling attachment, Pl. **29**, Fig. 1, may be used.

The belt driving the wheel must be allowed to traverse with the saddle. This can be arranged for by (i) driving from a long drum, D on Pl. **32**, Fig. 4, on the countershaft, or (ii) permitting the pulley on the countershaft to traverse, taking its drive from a spline or keyway in the countershaft.

6. **Revolution and travel of work.**—No definite speeds can be laid down for the revolution of the work, since the best speed depends upon the size and material of the work and the grade of the wheel.

Normal practice is from 20 to 140 ft. per minute surface speed, a higher speed being used generally for large diameter work than for small. The travel of the wheel or work longitudinally must be correlated to the revolutions of the work. Normally, the travel per revolution of the work is from two-thirds to the full width, W on Pl. **32**, Fig. 5, of the face of the wheel. If the travel is less than half the width, the wheel tends to wear convexly, since the edges have more work to do than the centre. If it is more than the full width, part of the work is not ground.

7. **Internal grinding.**—Holes may be ground internally by means of an internal grinding spindle, Pl. **32**, Fig. 3, either in a lathe or cylindrical grinding machine, if the work can be carried upon the face-plate or chuck.

Work difficult to revolve upon a lathe spindle, such as a block of cylinders, is best ground on a special cylinder grinding machine, the principle of which is shown on Pl. **32**, Fig. 6. The grinding wheel quill, G, is driven independently by a belt, B, kept taut by jockey pulleys and weights. G runs on a rigid spindle, O, whose eccentricity with regard to the main spindle, S, is adjustable. The work remains at rest; the eccentric movement of the grinding spindle, O, produces the necessary travel of the wheel round the cylinder.

8. **Surface grinding.**—Plain surfaces may be ground satisfactorily by substituting a grinding wheel for the cutting tool in a planer or shaper, provided a sufficiently rapid cross traverse can be obtained. Surface grinding machines are of the same general form as planers or shapers, with special dust protection for the sliding surfaces.

Normally, the work is made to traverse longitudinally a little more than its length (to ensure that it is ground right up to the end), with a speed of about 60 ft. per minute.

There are two methods of ensuring equal grinding all over the width of the work:—

i. The grinding wheel is made to traverse rapidly to and fro across the work, so that its trace is a wave line overrunning the work a little, Pl. **32**, Fig. **7**.

ii. The wheel is made to cut upon its flat side, and is wider than the work, A on Pl. **32**, Fig. **8**. The wheel, W, is cup-shaped, to allow it to be held on to the spindle by a nut and washer inside the cup.

Method (ii) has the advantage that the surface speed of the wheel does not decrease as it wears down. It entails the provision of more power, since a larger area of the wheel is always in contact, but it enables softer wheels to be used and greatly increases the rate of removal of metal.

9. **Tool grinders.**—Machines for grinding ordinary lathe tools, twist drills, &c., are usually of the pillar form shown on Pl. **32**, Fig. 9.

A rest, R, is provided, which can be set to any angle, so that every face of the tool can be ground as desired without any guesswork. The side of the wheel should be used for any work requiring great accuracy ; cup wheels are, therefore, more suitable than discs. *See also* Sec. **45**, para. 15.

10. **Universal grinders.**—Universal grinding machines can be made to grind plain surfaces, slots, &c. Flat work is bolted or clamped down to the table. Cylindrical work can be done by fixing to the table a headstock and a tailstock carrying centres. Irregular work, such as grinding the teeth of cast gears, sharpening milling cutters, taper reamers, taps, &c., can be done by adding a dividing plate to the headstock.

Wheels of the necessary form must be obtained, and kept to the correct shape by occasional trueing. Pl. **32**, Fig. 10, shows a method of sharpening a tap. Pl. **32**, Fig. 11, shows a milling cutter being relieved, or *backed-off*, and Pl. **32**, Fig. 12, shows one being ground upon the cutting face. The necessary rests are not shown in these figures.

11. **Selection of wheels.**—In modern practice, emery is seldom used in wheels. Purer forms of abrasive crystals, known as carborundum, corundum, alundum, &c., are employed.

Wheels are classified according to—

i. *Grade*, which is a measure of the hardness of the matrix.

ii. *Grain*, or *grit*, which refers to the size of the crystals in the wheel.

12. **Grade.**—Grade affects the rate at which metal may be removed, and should be carefully selected to suit the work.

Hard wheels hold the crystals more firmly and, therefore, longer. If they are too hard, the crystals are still held after (*a*) they have become blunt or glazed when taking a light cut, (*b*) the spaces between them have filled with metal when taking a heavy cut. In either case the wheel ceases to cut. Soft wheels allow the crystals to break out easily. They do not glaze or fill, but wear away rapidly. Small diameter work or narrow wheels necessitate a fairly hard wheel, while for large diameter work, the larger area of matrix in contact enables a softer and, therefore, freer cutting matrix to be used.

When the material of the work is hard, the wheel glazes easily, and, therefore, a soft wheel should be used, in spite of the fact that it will necessarily wear rapidly.

For grinding soft material, a harder wheel can be used, because the crystals will not blunt so quickly and, therefore, need not break out so soon ; hence the wheel will last longer. Generally, the softest wheel that will stand the stress without unduly rapid wear or without breaking up gives the freest cutting and the best result.

Fast revolution or traverse of the work causes greater stress upon the wheel, and so increases its rate of wear. Slow revolution of the work, therefore, makes possible the use of the softer grades of wheel.

Makers of grinding wheels manufacture a very large range of wheels and should be consulted—full details of work and machine being given—to enable the most efficient selection to be made.

The following general statements may be taken as a guide :—

Hard wheels are used on soft materials and soft wheels on hard materials.

Wheels to hold sharp edges and corners should be fine and hard.

The larger the area of contact, the softer and coarser the wheel.

Rapidity of cutting is increased by using a softer or coarser wheel.

Finish is improved by using a finer and softer wheel at a higher speed and lower traverse and with ample lubricant.

Increasing the wheel speed gives the effect of a harder wheel, and decreasing it gives the effect of a softer wheel.

The operator must be able to recognize the symptoms at once and apply the correct remedy to obtain the best result upon each piece of work, as a small difference in hardness may necessitate a change in work speed.

13. Grain.—The size of grain affects the rate of cutting. Naturally, large grain makes a heavier cut possible without filling up the spaces between the crystal points with metal.

Small grain necessitates very fine feed, and, therefore, little metal is removed, but it leaves a fine polish if the other details are correct.

Grain is measured by the mesh of a sieve through which the abrasive will pass, 100 being a fine grain and 10 a coarse. A moderately coarse grain, such as 36, will give free cutting and a good enough surface for all ordinary purposes, such as spindles and bearings. For rougher work, such as sharpening chisels and large roughing tools, 16 will grind faster than 36, with less likelihood of spoiling the temper of the steel.

14. **Width.**—The widest wheel should be used that can usefully be applied to the work in the machine available. Wide wheels take more power to drive, but produce more work in proportion and better surface, because they make it possible to set a larger travel and, therefore, more even distribution of the heat evolved.

15. **Mounting wheels.**—To ensure safety and reasonably long life for an abrasive wheel, it must be mounted upon the spindle with great care. The wheel must be held entirely by two side plates, which should be at least half the diameter of the wheel, and they should grip the wheel near their outer rims only, as shown on Pl. **32**, Fig. 6, and fit the spindle firmly. The wheel itself should not touch the spindle, as if a wheel is forced on there is a danger of starting cracks. It is considered good practice to use a wheel with a larger hole than the shaft, filled with lead, and accurately bored out to fit the shaft. Between each side plate and the wheel should be placed a sheet of rubber or several thicknesses of soft blotting paper. Thus no metal touches the abrasive wheel, it is reasonably free to expand in every direction, and all pressure is well distributed by soft materials. The plates are normally held together by a shoulder and nut, with spacing collars if necessary. The nut must not be tightened more than is needed to hold the wheel reasonably secure.

Balancing is best achieved by drilling shallow recesses in the wheel near its centre, filling them with a little more lead than is necessary, and cutting out the lead afterwards to the correct weight, as found necessary. A little attention to the balance may be necessary after each dressing or trueing.

A wheel which is in the least degree eccentric on its spindle will naturally grind only upon part of its circumference, and hence produce chattering. If it is quite true but out of balance it will cause its spindle to spring, and this will also produce chatter. A small amount of chatter spoils the surface of the work; a large amount may break the wheel. It is important, therefore, that wheels shall be true, both on the edge that is to do the work and also in thickness, which affects the balance.

16. **Dressing wheels.**—A wheel is *dressed* with a hard steel wheel or boss dresser, which is pressed against the wheel while the latter is revolved at about half normal speed. The dresser crushes the matrix, and so the wheel can be formed approximately as desired, and a sharp crystalline surface is left.

17. **Trueing wheels.**—A wheel is trued with a blunt diamond point in a suitable steel holder, taking a very light cut at normal speed. A fixed rest must be used for trueing *formed* wheels. Castings can be fettled and rough tools can be ground on a merely dressed wheel. Accurate work requires a diamond-trued wheel, properly balanced and running in closely fitted bearings.

18. **Lubricant.**—It is not only necessary when grinding accurate work to keep the metal below the temperature that would spoil its temper, but, moreover, the temperature of the whole work must be kept uniform during any one pass of the wheel, in order to prevent distortion, due to local heating and expansion. The temperature of the lubricant is unimportant, provided there is a copious and absolutely continuous supply. A reciprocating pump is not suitable, because the liquid arrives in gushes. A centrifugal pump, giving an absolutely continuous stream, is essential. A good lubricant is a solution of common soda in water ($1\frac{1}{2}$ lb. to the gallon). If the water is hard, 2 per cent. of soluble oil should be added. This solution will prevent rusting of both the work and the machine.

After use, the lubricant contains grit and metal grindings, and it should be allowed to drop these in a large settling tank before it is pumped round again. The use of clean oil enables a wheel to cut more freely and to produce a smoother surface.

19. **Guards.**—Grinding wheels should never be used without effective guards. The best type is one which completely encloses the wheel, except for the small part of its circumference which must necessarily be left exposed to enable it to reach the work, as shown on Pl. **32**, Fig. 9.

A wheel may burst at any time, and the fragments will then fly with great force. The guard must be strong enough to stand the shock of a wheel breaking up in it. Good guards also diminish the danger of affecting the lungs of operators by keeping in the abrasive dust, which lubricant does not entirely do. An operator should wear a mask or respirator if employed continuously on grinding work and should always wear goggles. Guards should be made of steel or wrought iron, not cast iron.

20. **Belt drive.**—It is essential that grinding wheel spindles shall be driven with the least possible amount of vibration or jolting, since either reduces the quality of the work and increases the danger of the wheel breaking up.

It is also essential that the speed of the wheel shall be reasonably constant, *i.e.* that belt slip shall not be excessive or irregular.

Leather belts are normally used, driving on to small pulleys on the spindles. These belts must be kept sufficiently tight, either by arranging good drives as nearly horizontal as possible or by fitting well-arranged jockey pulleys of large diameter, kept up to their work by springs or weights. The belts must be light, very flexible, endless, and of uniform weight throughout. Long diagonal glued joints must be made, and no other method of joining leather belts must be permitted.

Light canvas belts must be made up endless, by overlapping the canvas throughout the length of the belt, as this gives even weight throughout.

21. **Electric drive.**—Grinding wheel spindles are often driven by means of small electric motors, the armatures of which are built up on the spindle. Such a machine may give excellent results, provided that :—

i. The armature is truly balanced.

ii. The bearings are massive, true, and properly adjusted to give easy running without perceptible play.

iii. The bearings and the whole motor are adequately protected from abrasive dust and metal grindings. Otherwise, the bearings would wear excessively, and the poles of the motor would clog with the steel dust which would be drawn into them.

48. *Manufacturing machinery*

1. **Scope.**—Semi-automatic and automatic machines are devised to enable :—

i. Unskilled labour to turn out accurate work in repeat orders, when once the machine has been set up for the particular piece by a skilled man.

ii. A skilled man to turn out more work by attending several machines, any one of which requires attention at regular intervals only.

2. **Semi-automatic devices.**—The elementary principle is seen in the lathe shown on Pl. **27**, Fig. 6. The stop, T, can be placed upon the bar, U, so that when the boring operation is completed the finger, V, on the saddle will engage T and push over the lever, W, and stop the traverse. The lathe will then run idle, and no damage will be done if the operator is unskilled, or if he is attending another machine when the cut finishes.

3. **Capstan lathes.**—Pl. **23**, Fig. 1, shows a capstan lathe as an example to illustrate para. 1 (i). This lathe is of a

semi-automatic type. It requires a skilled man to set the tools for any particular piece of work, after which a man with very little skill can turn out any number of articles of that particular kind.

The capstan, C, can carry six automatic tools, and there are two cross slides. The knob, shown on Pl. **23**, Fig. **3**, is typical of the work that can be done by semi-automatic and automatic machines. Referring to Pl. **23**, Fig. 2, the operations are :—

i. The automatic chuck, K, is opened by pulling the lever, L. The bar of the *stock*, B, is run forward against the stop, S, which controls the length protruding from the chuck, and the chuck is closed again. The capstan is run back by means of the handwheel, H, and automatically turns through 60°, presenting the next tool to the work.

ii. The drill, D, is brought up to the work by turning H, and drills out the hole. It cannot be driven in too far, because the stop, A, comes up against J, when the operation is complete.

iii. The saddle carrying C is run back again, turns, and presents the next tool, a box-tool, T, which is also provided with a stop like A. T then turns down the end of the bar to the correct length and diameter for the screw, leaving the faces, E and F, completed.

iv. The capstan is withdrawn, and the next advance brings up the steady bearing, V, which engages the part turned down in (iii).

v. The slide holding the forming tool, W, is then brought up to the work to turn the curved portion by means of the lever, M. This slide has also stops which prevent the work being turned too small. The work has now the appearance shown on Pl. **23**, Fig. 3, which also shows the tool and steady.

vi. The capstan next presents the automatic die-box, X, which cuts the threads on the screwed portion, flies open when it comes up against the shoulder, F, and permits withdrawal without stopping the spindle.

vii. The other slide, carrying the parting tool, Y, is then brought up by pulling the lever, Z, and cuts off the completed work.

The box-tool, T, is shown enlarged, inset on Pl. **23**, Fig. 2. The tool has one edge to face, E. F is faced by the same edge that pares off the bulk of the metal. Steady rollers run on the completed work, and so enable a very heavy cut to be taken.

4. **Automatic machines.**—The action of a fully automatic machine is similar to that of a capstan lathe, except that instead of a man advancing the capstan each time by turning a hand-wheel, cams fixed to a slowly-revolving drum engage a projection on the saddle carrying the capstan, and make it advance and withdraw precisely as required—quickly when doing no work, and at a suitable feed speed when cutting. An automatic device is also fitted to change the spindle speeds to suit different operations, such as drilling and former turning. The chuck is also opened automatically after each piece has been cut off, the bar running forward, pulled by a weight, until stopped by S on Pl. **23**, Fig. 2. Time may be saved by combining operations, as, for instance, in the case explained above, the drill, D, might be mounted in the same face of the capstan as the box turning tool, T, and so operate simultaneously; also the die-box, X, can be arranged to run forward during the early part of the forming operation of W, and before the cut is very broad.

Similarly, if the hole were to be tapped, the tap, carried on the empty face of the capstan (Pl. **23**, Fig. 2), could be run in during the forming, the tap revolving the same way as the work, but at half-speed, since taps must cut slowly; then the tap could be withdrawn without affecting the work, by speeding up the tap to twice the work speed.

Very complicated gearing would be required in this case, but could be effected easily by means of shifting belts in a machine specially designed for automatic tapping.

49. *Testing machine tools*

1. **Testing lathes.**—Machine tools become inaccurate in the course of time, owing to wear and the occasional heavy stresses due to accidents, such as tools cutting in and breaking. The following tests, applicable to a lathe, can also be applied with slight adaptation to any other machine tool.

i. *Testing head centre.*—Test made with a centre tester, Pl. **24**, Fig. 15.

(*a*) If the centre is not true, grind accurate and test again.
(*b*) When true, remove the centre, turn it through 180°, replace, and test again. Any inaccuracy now shows that the hole in the spindle nose is inaccurate.
(*c*) Clean out the hole carefully, and repeat tests (*a*) and (*b*). The inaccuracy may be due to dirt alone.
(*d*) If still inaccurate, the indication is that the spindle is warped, and the taper hole needs grinding with an internal grinding attachment, after the bearings have been adjusted.

ii. *Testing tail centre.*—Place in the tailstock a centre which has been ground true in an accurate lathe, and turn up between centres a cylindrical bar of steel, taking care that the tool is precisely at the height of the centres. Measure the diameter of the turned bar at the ends with a micrometer calliper. Any difference in diameter indicates that the tail centre is not truly opposite the headstock. No attempt should be made to remedy this until the lathe bed has been trued.

iii. *Testing lathe bed.*—

(*a*) *For lateral accuracy.*—Turn up between centres a cylinder of steel as long as can conveniently be held, and large enough in diameter to be stiff against whip, *e.g.* of a diameter about equal to the height of centres. Measure carefully the diameter every few inches. Any irregularity in the diameter indicates that the vertical sides of the shears, C on Pl. **25**, Fig. 3, are worn hollow in places. A regular increase or decrease in diameter merely indicates inaccuracy of the tail centre setting.

(*b*) *For vertical accuracy.*—Take a light cut with a tool specially made to cut at either top or bottom of the work, instead of at the side as usual, Pl. **23**, Fig. 4. Measure as in (*a*). Any irregularity indicates wear of the top surface, A, of the shears, Pl. **25**, Fig. 3. A regular taper indicates that the tail centre is high or low.

iv. *Testing the leadscrew.*—The threads can only be tested for accuracy in a special thread-testing machine. Being used for screw-cutting only leadscrews retain their accuracy for long periods, but it is necessary to ensure that the faces of the thrust collars are in good condition.

v. *Testing the shears on the saddle.*—Face a disc of steel firmly held in a good chuck or on a face-plate. Inaccuracy in two forms should be looked for :—

(*a*) The disc may be found to be hollow or humped in the centre, indicating that the shears are not at right angles to the spindle. The error may be in the shears or in the spindle, or partly in both.

(*b*) The disc may have circular high bands, due to wear of the shears on the saddle and of the gibs on the cross slide. The gibs get slack and require renewing periodically.

vi. *Testing alignment of headstock with bed.*—Place a stiff bar of steel in a chuck and turn it down, using the back centre

to support it, till true all over. Slack back the tail centre and take a light cut all along. Any considerable taper indicates inaccurate lateral alignment. A very slight increase in diameter towards the tailstock end may be caused by whip in the work. Vertical alignment can be similarly tested with a tool as shown on Pl. **23**, Fig. 4.

vii. *Testing alignment of tailstock with bed.*—Draw the quill of the tailstock well back into the body, and turn up a test piece of work between centres, measuring it carefully. Unclamp the tailstock from the bed shears and force it away from the work by screwing forward the quill. Take another light cut in this position. Any considerable taper, or change of taper, indicates that the quill does not run out parallel with the bed.

2. The operations described in para. 1 (ii), (iii), (v), (vi) and (vii) correctly indicate the principles involved, but they are somewhat old-fashioned and are all much more easily and accurately carried out by means of a standard mandrel (Pl. **27**, Fig. 3) and a dial test indicator (Pl. **22**).

3. **Trueing up a lathe.**—The first surfaces to be trued should be those of the bed shears, since these form the main framework of the lathe, and no subsidiary surfaces, such as saddle or slide-rest vees, can be satisfactorily tested until the bed is true.

i. *Top surfaces.*—A long, wide straight-edge, or narrow, long face-plate, should be lightly smeared with red lead or venetian red, applied to the top surfaces after careful cleaning and moved about a little after application. The top surfaces, all treated as one face, should be scraped to fit well to the face-plate everywhere.

In the removing of metal it must be borne in mind that the final surface must be parallel with the axis of the head-stock spindle, and that the bed is more likely to be worn down near the centre and at the headstock end than under the tailstock; *see* para. 1 (vi).

ii. *Side surfaces.*—The surface which normally controls the accuracy of the cut is that shown at D on Pl. **25**, Fig. **3**. This surface should be scraped up to fit a straight-edge, observing the same precautions as in (i), viz., that it is made parallel to the axis of the spindle if the headstock is fixed.

iii. *Secondary surfaces.*—The under side and the outer edge, C on Pl. **25**, Fig. 3, of the bed are secondary to the top and inner edge, D, respectively. They must first be brought parallel to their primaries, A and D, by callipering the thickness of metal between them, and scraping down in certain chosen spots. The surface can then be fitted to a straight-edge.

The best test of the accuracy of this work is to assemble the saddle, tighten its gibs slightly, and move it by hand along the bed. Any local binding or looseness shows inaccuracy.

iv. *Saddle and slide-rest vees.*—

(*a*) The primary vees, which take the pressure and guide the tool, should be trued first, beginning with those under the saddle and working upwards in rotation to the top slide.

(*b*) The vees on the top of the saddle must be truly at right angles to the side of the bed.

(*c*) Both the saddle and slide-rest vees must be straight, and brought true to a surface plate.

(*d*) The secondary vees, which the gibs engage, must then be brought truly parallel to the primaries, and surfaced.

(*e*) Each adjusting gib should be trued to a surface plate.

v. *The spindle* should be ground or lapped true, and its bearings fitted as described in Sec. **37**, para. 9.

50. *Power to drive machinery*

1. The power required to drive any machine can be obtained from its maker, or failing that, an examination of the driving arrangements will usually afford sufficient guide, *e.g.* if a machine is belt-driven, it can usually be assumed that a single leather belt is intended to be used, and the power which can be transmitted by this can readily be ascertained (*see* Sec. **151**). A good rough rule is 1 H.P. per in. width of belt, for single leather belts up to 3 in. wide.

The power required for a given machine will depend on whether carbon steel or high-speed steel tools are to be used, and in the latter case also on whether the design of the machine will permit the tools to be used at their maximum cuts and speeds. Old-fashioned machines designed for carbon steel tools (of which many may be met in the service) will not stand the strain of these heavy cuts, but usually have sufficient margin of strength to permit the power to be doubled if high-speed tools are used; a modern machine of the same size, unless lightly built either for cheapness or for portability, will usually allow the maximum cut to be taken, but there is no point in providing the necessary power (which may be 6 to 8 times that required for carbon steel) if high-speed tools are not available.

Small machines frequently do not allow for the maximum cuts with high-speed tools, the reason being that the work dealt with in these machines is usually too light to stand the strain.

Table L gives suitable powers for various machines, the minima being for old-fashioned light machines using carbon steel tools, and the maxima for modern heavy duty machines with high-speed tools.

TABLE L.—*Power required to drive machine tools*

Lathe, 6-in. centre	1– 5 B H P.
Lathe, 12-in. centre..	2–12
Planer, 2 feet × 2 feet (one tool box) .	3– 5
Planer, 5 feet × 5 feet (two tool boxes)	15–20
Shaper or slotter, 12-in. stroke	3– 5
Sensitive drill, taking 1-in. diameter .	1– 2
Radial drill, taking 2-in. diameter ..	4– 6
Cylindrical grinding machine, 8-in. swing	2– 5
,, ,, ,, 15-in. swing	5–15
Surface grinding machine, 12-in. wheel ..	15

From this table and from other considerations, the total maximum horse-power for all the metal-working machines in a shop can be estimated.

2. **Diversity factor.** -Unless there are special reasons to the contrary, it is safe to assume a diversity factor of three, that is, to assume that one-third of the machines will be working at full power at any one period, and to instal horse-power sufficient to meet this assumed demand. In the case of a sawmill the conditions are rather different, and are dealt with in Chap. X.

3. Having estimated the power required, a suitable prime mover must be chosen (if no electric power supply is available). *See* Part II, Chap. XXXI, for considerations affecting the choice.

It should be remembered that steam engines can work up to their full rated power without undue wear, but that oil, gas, and petrol engines should not be continuously pressed to their full rated power, if long life and freedom from break-down is aimed at.

Suppose X horse-power is required to drive a shop. If steam is used, instal an engine rated at X horse-power, plus any allowance for extensions. If an oil or gas engine is used, instal an engine rated at $\frac{100X}{80}$ H.P. If a petrol engine, instal an engine rated at 2X H.P.

For the application of electrical power, reference must be made to the Textbook of Electrical Engineering.

CHAPTER X

WOOD-CUTTING MACHINERY

51. *Introduction*

1. The **circular saw** is required in engineer workshops both in peace-time and war; its various processes are, therefore, described at length. The process requiring most attention is the sharpening and setting of the saw. The band saw will be little used for large work, owing to difficulties of installation and the skill required for manipulation and sharpening. Experience has shown that the large band saw is not suited to military requirements, although in civil establishments its two advantages, less power to drive and less sawdust formed, are now recognized. Small band saws, not designed for the conversion of timber but for sawing small pieces into intricate shapes, are of great use in connection with joinery manufacture and patternmakers' work.

2. The **frame saw,** used for conversion of logs, &c., may, like the large band saw, be met with by the military engineer; he should know its principles of working, but it will not normally be a machine with which he works.

The various joiners' machines, *e.g.* planers and thicknessing, morticing, tenoning, and moulding machines, will be met with in peace-time.

3. **Woodworking machinery,** although apparently simple to work, really requires considerable knowledge of detail and skill to work successfully. Great care on the part of the operator is. also required, or serious accidents will occur. It is for this reason that only sawyers and wood machinists, who realize the danger, should normally be permitted to manipulate woodworking machinery.

52. *Forms of saw teeth and their sharpening*

1. The teeth of all saws used for cutting timber, whether hand, circular, band, or frame, are made and sharpened in accordance with the following principles :—

i. For *ripping* timber, or sawing in the direction of the grain, the tips of the teeth are sharpened to a chisel point, Pl. **33,** Fig. 1; the tips do the cutting, removing small chips of wood.

ii. For *cross-cutting* timber or sawing across the grain, the teeth are sharpened to a sharp point and have a sharp edge, Pl. **33,** Fig. 2 ; the point and edge cut through the fibres of the wood, removing sawdust only.

A cross-cut saw is unsuitable for ripping.

A rip saw is frequently used for cross-cutting, but it is not so suitable for this purpose as a cross-cut saw.

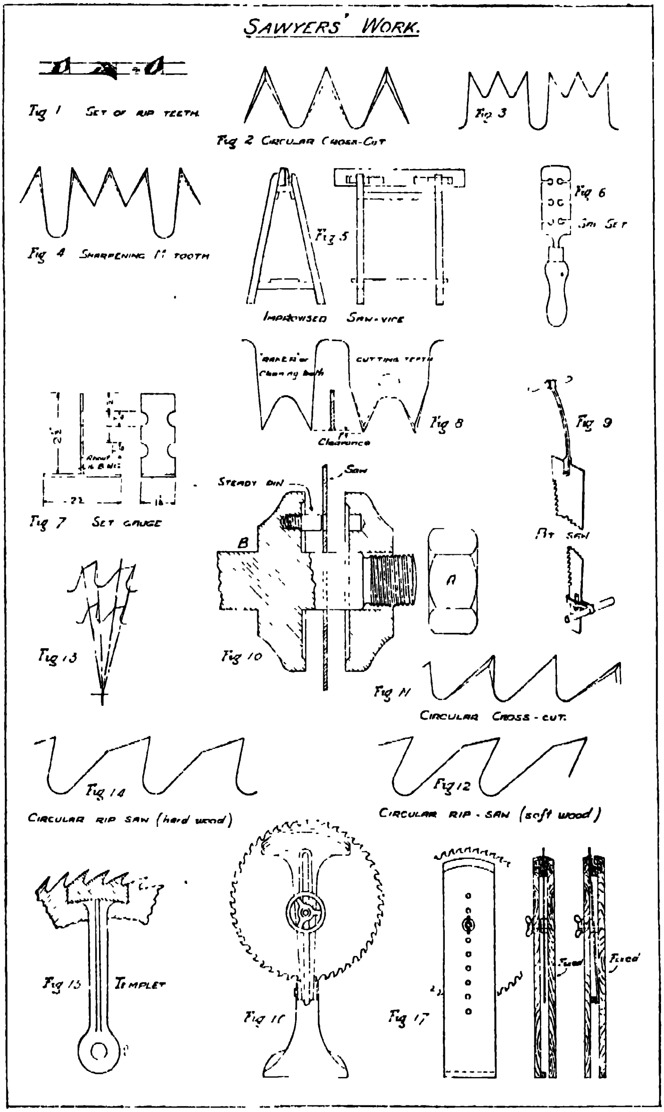
iii. If the thickness of the saw is the same at the teeth edge as the remainder, the latter will bind in the cut that has been made by the teeth. To avoid this, the width of the cutting edge of the blade is made greater than that of the remainder ; the most usual method is to bend alternate teeth out on opposite sides, Pl. **33,** Fig. 1. This is known as giving *set* to the saw.

iv. If the space between two adjoining saw teeth is too small, sawdust will tend to jam in that space and impede the cutting action. Hence the teeth are made to project some considerable distance from the body of the blade, in order to increase the area between the front of one tooth and the back of another.

2. The procedure for sharpening hand saws for general use is given in para. 4 ; such saws are required both for ripping and for cross-cutting. If much ripping is to be done by hand, the teeth of the hand rip saw should be filed straight across, without bevel, in the manner described in Sec. **53** for circular rip saws.

3. The *saw, cross-cut,* 3 *feet* and the *saw, cross-cut,* 5 *feet,* both service articles, have what is known as the M tooth, Pl. **33,** Fig. 3, and cut in both directions of the stroke. The cutting edge is curved ; care is necessary to ensure that all teeth are exactly the same length, as short teeth will not do their share of the cutting. The correct method of sharpening is shown on Pl. **33,** Fig. 4, and tracings of the teeth, when new, are shown on Pl. **33,** Fig. 3 and Pl. **35,** Figs. 4 and 5. The edges of the teeth are bevelled off at 45° to obtain a sharp point with which to cut through the fibres of the wood. If the teeth are filed so that they become longer than shown on Pl. **33,** Fig. 4, they will be unduly weak, especially when cutting hard wood. As the points are continually sharpened, the teeth will become shorter, less acute, and less capable of taking a sharp point. Moreover, as the gullets become shallower, there will be a greater tendency for sawdust to choke the saw and impede the

PLATE 33.



[*Figs.* 2, 4, 5, 6, 7, 8, 9, 11, 12, 14, *and* 17 *reproduced from "Saws; their Care and Treatment" by permission of Messrs. William Rider & Son, Ltd., London, E.C.4.*
Fig. 16 *reproduced by permission of Messrs. A. Ransome & Co., Ltd., 63, Queen Victoria Street, London, E.C.4.*]

cutting action; this will be more marked when cutting soft and wet woods than when cutting hard and dry woods. The teeth should be kept as far as possible to the original trace given on Pl. **35**, Figs. 4 and 5, except that with very wet soft woods the depth and acuteness of the teeth may be increased, and with hard woods decreased. The procedure to adopt with old and worn cross-cut saws is as follows:—

i. Range down the tips of the teeth with a file until they are all the same length. The saw should be gripped in some form of improvised vice, as shown on Pl. **33**, Fig. 5.

ii. File down the centre tooth of the M with the file held straight across, until the correct depth, Pl. **33**, Fig. **4**, is obtained. Then file the side teeth and gullets.

iii. File two 45° bevels on each tooth, the bevels on alternate teeth being on different sides, Pl. **33**, Fig. 4.

iv. Set alternate teeth in opposite directions; this is done by the saw set, Pl. **33**, Fig. 6. The amount of set varies according to the hardness of the wood to be cut. A simple gauge, Pl. **33**, Fig. 7, although not essential, is useful in obtaining uniformity.

Cross-cut saws with *raker* teeth are sometimes met with, Pl. **33**, Fig. 8. The raker teeth are made shorter than the cutting teeth by an amount not exceeding $\frac{1}{16}$ in. and their sole function is to clear away the sawdust, not to cut. Such teeth are usually swage set, Pl. **34**, Fig. 1. Raker teeth are useful for wet and soft woods. It will be found that service cross-cut saws, when first used, have the centre tooth of the M shorter than the others, and are given ordinary side or spring set.

4. **Hand-saw sharpening.**—The three most common cases are the following, and they will be treated separately:—

i. When the teeth simply require pointing to increase the cutting power.

ii. When the teeth, owing to frequent pointing, become irregular (as shown at *a* on Pl. **35**, Fig. 1) and require a more extensive adjustment.

iii. When the teeth are so very irregular as to require removal and replacement by new ones.

i. Secure the saw in a vice between two strips of wood at a suitable height, and hold the file in such a manner that the plane of the cut made by the file exactly corresponds with the existing surfaces; first cut the teeth on one side and then reverse the saw and cut those on the other side.

ii. Fix the saw as in (i). Hold the file at right angles to the blade in both directions, as shown at *a* and *a* on Pl. **35**, Fig. 2, and cut down between each two teeth till all are exactly the same size, irrespective of their relative heights, as shown at *b* on Pl. **35**, Fig. 1. This method is much better than taking alternate teeth, as in (i). The cutting face of the teeth must be filed so as to fall backward about 12°, thus making an angle of 78°, as shown at *c* on Pl. **35**, Fig. 1 ; this is done by setting the bevel at the proper angle and testing the filing from time to time. This angle gives the best results for general work.

Next reduce the teeth to a common level, which is done by lightly rubbing off the higher points with a file run down the whole length of the saw and carefully re-sharpening them, removing a portion from each side of the tooth, as shown by the dotted lines at *b* on Pl. **35**, Fig. 3. This keeps the teeth the proper size, or as they were when first produced. Several such runnings down will make a good, even, level surface, which should be either straight or slightly convex, as the tendency is for the saw to wear hollow.

To set the saw.—This is done by bending the teeth alternately outward with the aid of a saw set, or, if it is done judiciously, with a punch made by breaking off the point of a worn-out file, tempering it and grinding it flat. In the latter case, the saw should be held on the end grain of a piece of hard wood, and the punch struck with a light hammer. For a dovetail saw this method is better than using a set, as the teeth are so small that unless the set exactly fits the blade, the latter is likely to be bent and *crippled*, instead of the tooth only being bent. This will occur with all saws if the set is too low down on the teeth.

If the timber to be cut is dry, very little set is necessary, as it increases the labour of cutting and wastes the material; it is, however, important that all the teeth should have the same amount of set, and it must be remembered that inferior sharpening often leads to the mistaken idea that a saw requires more set.

The teeth should now be adjusted to the proper angle for cutting, and an angle must be given which will answer for all general purposes, but which can be altered to meet special cases.

Start with the handle of the saw on the right hand, and, with the handle of the file 30° below the horizontal (*see b* on Pl. **35**, Fig. 2), and with about the same inclination toward the point of the saw (as shown at *b*), cut on the back of the tooth which is set away from the operator and which is nearest the handle. This cut should be as shown (correctly)

on Pl. **35**, Fig. 3, where 1 and 2 are correct and 3 and 4 are faulty.

While this cut is being formed, a like cut is being produced on the front of the tooth immediately behind this one, and the two surfaces should be so cut that when one of them is completely bevelled the other is in a like condition ; it is necessary for the whole of the squareness to be removed to ensure good results. The treatment of one of these hollows between two teeth is the same for all the others. Alternate hollows are dealt with on one side of the saw and then or the other.

If this operation is properly executed, the cross-section will be as shown at *b* on Pl. **35**, Fig. 1. A needle laid in the channel between the teeth should traverse the whole length of the saw when the handle is raised.

iii. When the teeth of the saw are in a very bad condition, it is quicker to remove them entirely and replace them with new ones.

To do this, file off the old teeth so that the surface of the blade is perfectly clean, and start the cutting from the handle end.

A half-rip saw requires about 2 teeth to the inch.
A hand saw requires about 4 teeth to the inch.
A panel saw requires about 8 teeth to the inch.
A tenon saw requires about 10 teeth to the inch.
A dovetail saw requires about 16 teeth to the inch.

Thus the division of an inch by these numbers gives the space each tooth should occupy.

Take the hand saw as an example. Cut the first hollow $\frac{1}{4}$ in. wide, and the extremity nearest the point of the saw will represent the point of the first tooth (*see* *c* on Pl. **35**, Fig. 3). Now start another hollow a little distance from the intended point, as shown, and gradually work back to the handle end, thus forming the tooth immediately behind. When this is done, the hollow can be made $\frac{1}{4}$ in. wide as before, and the process is repeated until all the teeth are cut in, when the second process can be carried out to complete the operation.

It is better first to measure the teeth to ensure that they are all the same size.

5. The **pit saw** is still a service article, and is shown on Pl. **33**, Fig. 9. It is used for ripping only, and the form of its teeth and their sharpening is similar to that of the circular rip saw, described in detail in Sec. **53**.

It may be useful in mountainous countries where the transport of machine-driven saws is impossible. It may also

be useful for breaking down large trunks of trees which are beyond the capacity of machine-driven saws.

A log is sawn by being placed over a saw pit. Two men are required, one standing on the log and the other in the saw pit below. The stroke of the saw should be from 3 to 4 feet. The cutting is done by the downward stroke, and the return upward stroke is held clear of the cut to avoid blunting the teeth.

53. *Circular saws*

1. **Circular saws** are secured to the revolving spindle of the saw bench by means of a nut, A on Pl. **33,** Fig. 10, which presses the saw against the collar, B. A steady-pin is provided on B to prevent the saw from revolving on the spindle. The saw has a central hole for the spindle to pass through, and a steady-pin hole. The spindle and steady-pin must be a good fit in their respective holes in the saw. Hence, in ordering saws for any particular bench, the following information (which also includes points to be dealt with later) should invariably be given :—

i. Whether the saw is for ripping or cross-cutting.
ii. Whether for hard or soft wood.
iii. Saw diameter.
iv. Spindle-hole diameter.
v. Steady-pin diameter.
vi. Distance between centres of spindle and steady-pin.
vii. Gauge of saw.
viii. Shape of teeth.
ix. Distance between points of teeth.

It is usually advisable to send paper templates of (iv), (v), (vi), (viii) and (ix).

However well the spindle and steady-pin may fit their holes, there will be some play when the saw is in position. To ensure that a saw is cutting as quickly and smoothly as possible, *the point of each tooth must be equi-distant from the centre of rotation* ; hence, a circular saw must always be put on to its spindle in the same way, which should be as follows :—

Revolve the spindle until the steady-pin is uppermost ; place the saw in position, and force it back against the direction of rotation, so that the *front* of the steady-pin hole is bearing hard against the steady-pin. Then, still holding the saw back on the pin, screw up the collar nut.

2. The **shapes of typical teeth** for cross-cut and rip circular saws are as shown on Pl. **33,** Figs. 11, 12, and 14 ; Fig. 12 represents a tracing from a 36-in. rip saw for soft wood. It will be noted that the front edge of the cross-cut saw, if

produced, is in front of the spindle hole, whilst in the case of the rip saw the front edge of the tooth, if produced, is behind the spindle hole. The following table shows suitable gauges and number of teeth for saws of varying diameters for general work in soft and medium woods; rough, knotty, and hard woods require saws from one to two gauges stouter.

	Rip saws		Cross-cut saws	
Diameter	Teeth	Thickness	Teeth	Thickness
In.	No.	S.W.G.	No.	S.W.G.
12	44	17	72	16
16	44	17	78	16
18	44	16	84	15
20	44	15	90	14
24	44	14	90	13
26	44	14	90	13
28	44	13	92	12
30	44	13	96	12
36	48	12	100	11
42	48	11	108	10
48	48	10	112	9
54	52	9	120	8
60	56	8	120	7

Generally speaking, the harder and less fibrous the wood to be sawn, the farther should the teeth faces of cross-cut saws slope back, and the more upright should those of rip saws be.

The military engineer must usually be prepared to accept the tooth form supplied by the manufacturer. On arrival of a new saw, a tracing of the teeth and a template should be made, to serve as a record when re-gulleting is required. Otherwise, teeth would tend to become uneven after repeated sharpening. After long service, it will be necessary to modify the size of the tooth as the saw diameter decreases; this may be done as shown on Pl. **33**, Fig. 13. A template of three teeth on a pivoted arm will ensure that teeth are sharpened and gulleted to a uniform and correct shape, Pl. **33**, Fig. 15.

New saws are received from makers unsharpened, but with set given. The set will have to be verified after sharpening.

3. **Sharpening a rip saw by filing.**—Assuming that the saw is not so far worn that the gullets require attention. First clean off any gummy deposit that may be on the teeth or in the gullets with a clasp knife and paraffin. Place the saw in position on the spindle, as described in para. 1, set the saw in motion, and gently apply a piece of emery or grindstone

to the edge. The stone should be held up against the teeth, care being taken to keep it square, so as to make the tops of the teeth parallel; at the same time it should be given a sideway movement to prevent the saw cutting a notch in its edge. The process should be continued until the tops of the teeth are running perfectly concentric with the saw spindle; this can easily be ascertained by examining the points of the teeth. The stoning-down process must be continued until the mark made by it appears at the extreme point of every tooth.

The saw is now ready for filing, and should be placed in a cramp, Pl. **33**, Fig. 16. Pl. **33**, Fig. 17, shows an improvised wooden cramp which acts well in practice. The top of the saw should be about 45 in. above floor-level, and the vice 12 inches wide. The files most commonly used for sharpening saws are triangular, round, half-round, and mill saw files. All files so used should have rounded edges, so as to avoid the risk of making sharp corners or nicks in the gullets. Files, saw, topping 10-in. with two round edges, are very suitable for this work.

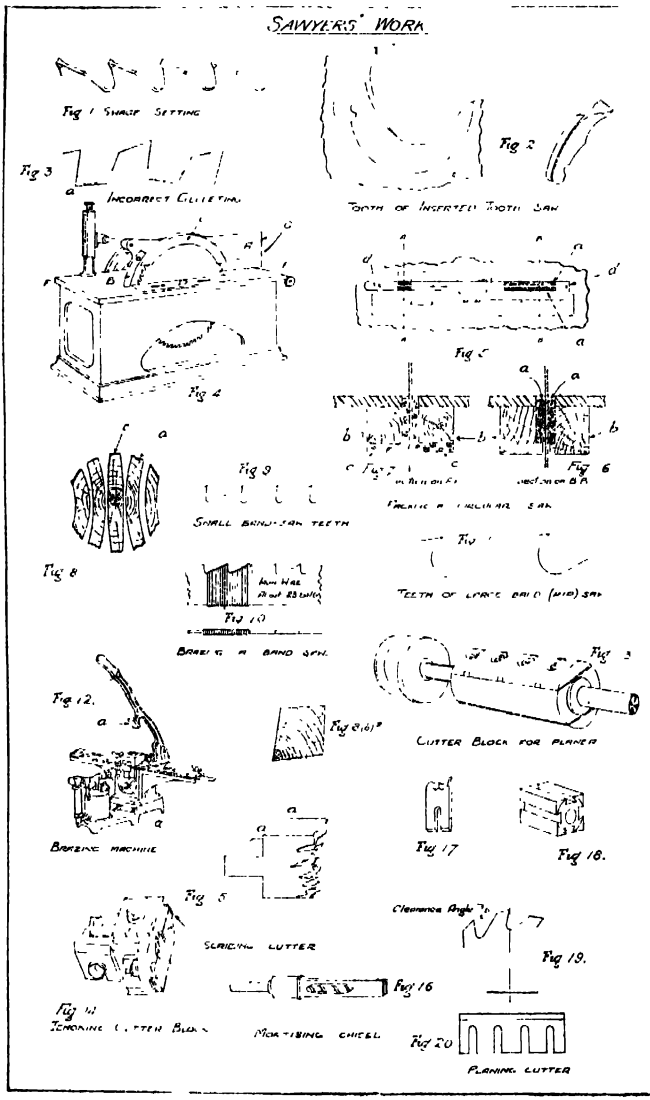
At this stage it must be remembered that a sharp *chisel point* is required, the line of the point being at right angles to the diameter of the saw. The teeth have already been given set, hence the tips of the teeth can be filed with the file held horizontally, which is an advantage. Should the teeth be unevenly set at this stage, it is advisable to roughly set them to the final position, so that the chisel points of each tooth may all be absolutely square across when cutting. In filing, first attend to the face of the tooth and file it straight across, at right angles to the saw, until the edges are sharp right angles. Work round every tooth in turn, taking as little as possible off each and preserving the shape of the gullet. The inclination of the teeth should not be altered.

The tips of the teeth have now to be filed in such a way that—

i. A sharp chisel point is produced.
ii. The points of all teeth are exactly the same distance from the centre of rotation of the saw.
iii. The shape of all teeth is uniform.

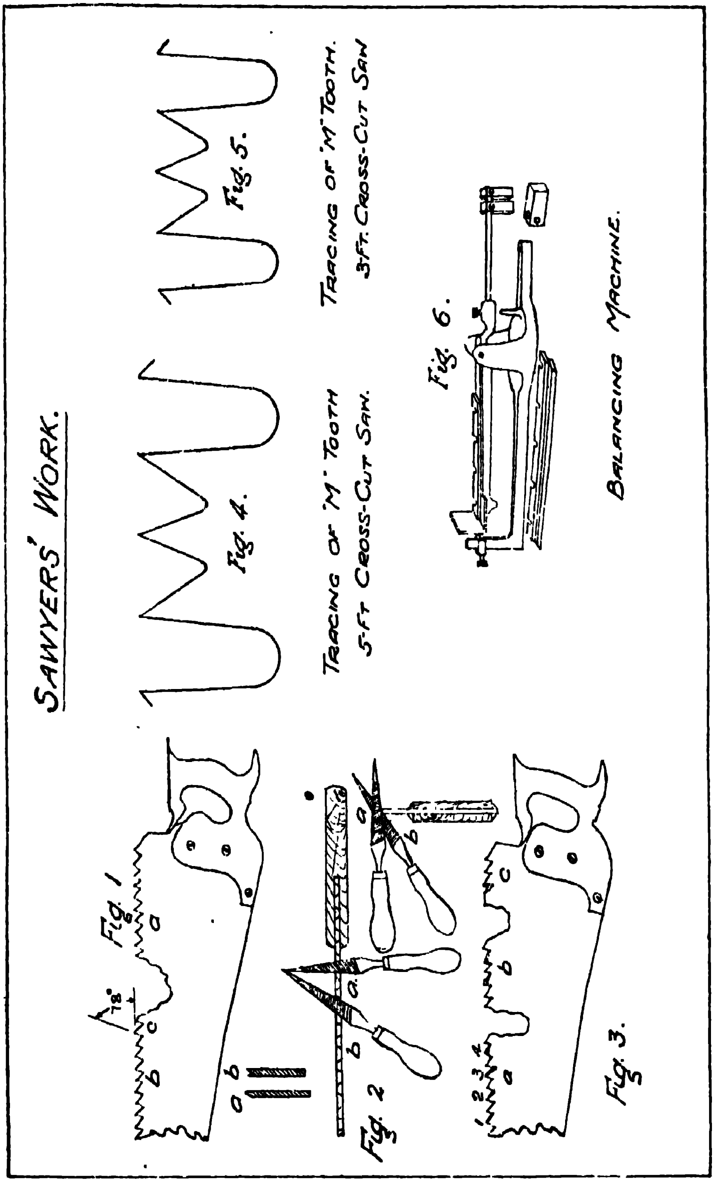
The stoning-down process has left a mark on each tooth, and to comply with (i) and (ii) the top of the tooth is filed from front to back so as to form a chisel point which is perpendicular to the plane of the saw (not to the tips of the teeth which are set over). Filing is continued until the mark of the stoning-down on the front face of the tooth is just eliminated. It is better to file the tops of all the teeth set

PLATE 34.



Figs. 1, 3, *and* 10 *reproduced from "Saws; their Care and Treatment," by permission of Messrs. William Rider & Son, Ltd., London, E.C.4.*
Figs. 2 *and* 12 *reproduced by permission of Messrs. C. D. Monninger, Ltd.,* 59, *Farringdon Road, London, E.C.*1.]

PLATE 35.


SAWYERS' WORK.
Fig. 1
Fig. 2
Fig. 3.
Fig. 4.
TRACING OF 'M' TOOTH
5-FT CROSS-CUT SAW.
Fig. 5.
TRACING OF 'M' TOOTH.
3-FT. CROSS-CUT SAW
Fig. 6.
BALANCING MACHINE.

towards the sharpener first, and then reverse the saw in the vice and file the others.

Regarding (iii), the inclination of the back of the teeth should be adjusted to a template. A clearance of 5° is generally sufficient, Pl. **34,** Fig. 19. If this is exceeded, the tooth is apt to become weak or to have insufficient *hook* or forward inclination; it is on the *hook* that the speed of the cutting depends. Saws thus filed can be re-sharpened with a few light strokes of the file. This re-sharpening process can be carried out three times before the saw requires stoning down.

It is the practice of some sawyers to put a bevel on the face of rip-saw teeth (*i.e.* not to file them straight across), and also to put a bevel on the top of the teeth (*i.e.* not to file them at right angles to the blade when the teeth are set). Whatever the merits of this practice, it should not be practised in the service.

4. **Setting.**—The set of the teeth should now be verified. The notch in the saw set, Pl. **33,** Fig. 6, corresponding to the thickness of the saw plate, is fitted over the point of the tooth, and held about $\frac{3}{8}$ in. from the top of the tooth; with a gentle pressure of the hand, each tooth is bent outwards in the desired direction (alternate teeth being bent in the same direction), and the actual amount they are bent must be verified by a gauge, Pl. **33,** Fig. 7, so that absolute uniformity is obtained. The edge of a properly set saw, in plan, is as shown on Pl. **33,** Fig. 1.

Spring setting.—No hard and fast rule can be laid down as to the amount of set to be given in any particular case, as it will vary with the diameter and thickness of the saw and the kind of wood being cut. As a guide, however, a 36-in. saw, cutting soft timber, should be given a set of $\frac{1}{32}$ in. on each side. If the saw is then found to bind, more set must be given. It is good practice to reduce the set to the least amount consistent with freedom of working, in order to avoid sawdust losses. If too little is given, however, the saw will tend to run very hot; any projections in the saw will be burnt and appear as *blue eyes,* and distortion of the saw will usually follow, necessitating re-hammering.

There are many types of patent saw set on the market, but the type shown on Pl. **33,** Fig. 6, is the most satisfactory. Set gauges are usually made by the sawyer.

Swage setting, in which the teeth are not bent outwards, but their tips are splayed, as shown on Pl. **34,** Fig. 1, is adopted sometimes for forest work, and gives very quick cutting. Saws so treated remove slightly more sawdust than when spring set. Special appliances are required for re-setting the teeth.

The inserted tooth saw, Pl. **34,** Fig. 2, which cannot be set in any other manner, possesses the following advantages :—

i. The diameter is constant for the whole of the life of the saw.
ii. Re-gulleting is eliminated.
iii. A worn or broken tooth can be easily replaced.
iv. The separate points can be made harder than is possible with teeth which form a part of the saw, and they, therefore, require repointing less frequently.
v. The body can be made of a less brittle material.

5. **Gulleting a rip saw.**—Rip saws should be re-gulleted when, owing to repeated sharpening, the gullets are not sufficiently deep to carry away sawdust from the cut, thereby impeding the cutting action of the saw. As a general rule, the depth of gullet should not be more than $\frac{1}{4}$ to $\frac{3}{8}$ in. less than that of the original tooth, a template of which should have been preserved. Saws are re-gulleted by one of the following methods :—

i. A fly press, in which case the teeth shape is stamped out.
ii. Filing.
iii. A gulleting machine, Pl. **37,** Fig. 1.

If templates are non-existent, the shape of the teeth should be based on Pl. **33,** Figs. 12 and 14. The bottom of the gullet should be well rounded.

Pl. **34,** Fig. 3, shows a common fault, the square gullet, having a sharp angle at *a*. Not only does sawdust bank up in the angle, but cracks are liable to start there.

When gulleting by hand it is inadvisable to gullet each tooth in turn owing to the risk of destroying the tension by the heat generated.

Gulleting by machine is dealt with in para. 14.

6. **Sharpening a circular cross-cut saw.**—The processes are :—

i. Stoning-down, as in the rip saw.
ii. Filing bevels on the front and back faces of each tooth, so that a very sharp point is formed at the extreme tooth tip for severing the fibres. Filing is continued until the stoning-down mark is just eliminated. The bevels are filed to an angle of 45° to the plane of the saw. A bevel is not carried down in the gullet, but is tapered off to nothing, Pl. **33,** Fig. 2. A bevel of 45° should never be exceeded, as the saw would then tend to dig in. Teeth with a smaller bevel are better for hard wood ; they cut slower but use less power.

7. **Setting cross-cut saw teeth.**—The bevelled edges are on the inside, alternate teeth being set in the same direction. About one-half the set required for rip saws is given to cross-cut saws, *i.e.* to a 36-in. saw, about $\frac{1}{64}$ in. on each side.

After repeated sharpenings the teeth will become stubby and less acute, resulting in clogging and slower cutting. When it is necessary to re-cut the teeth, they should be filed down to a template, straight across and neglecting the bevel. When the teeth have been filed to shape, the bevels are re-cut.

8. **Circular saw benches** can be divided into—

i. Those intended for both ripping and cross-cutting.
ii. Those intended for cross-cutting only.

Normally an engineer workshop will be provided with the former. Cross-cut benches will only be installed in base parks, &c., where the output is large.

Pl. **34,** Fig. 4, shows a type of plain bench suitable for rip saws up to 48 in. in diameter. The fence, A, guides the timber and holds it square to the blade, and it is adjustable as regards distance from the saw and inclination to the bench. A riving knife, B, to part the timber after cutting and to prevent the saw from binding, and an adjustable guard, C, must be fitted in pursuance of regulations issued by the Home Office Order, Section 79 of Factory and Workshops Act, 1901. The portion D is removable and discloses the collar nut at the end of the spindle, which is carried in two bearings and a third outboard bearing at the pulley side. Sometimes rollers are placed, as at FF, to facilitate the passage of timber off and on to the benches. Cross-cutting can be carried out on these benches, but the length and other dimensions of the work is limited, to prevent fouling in the driving pulley. Plain benches of this type supply most of the needs of the military sawmill.

For sawing up felled timber into scantlings, a form of rack bench, with either hand feed or automatic feed, Pl. **36,** Fig. 1, is used. Saws for such benches are made up to 72 inches in diameter; no fences are provided. Makers will supply portable benches of this type for pioneer work in forests, in which case the heavy metal frame is replaced by timbers obtained locally.

Circular benches with roller feed, Pl. **36,** Fig. 2, are useful for sawing thin boards from deals, planks, or battens, and are made up to 48 in. in diameter.

Self-acting chain (or rope) feed benches, Pl. **36,** Fig. 3, will cut small logs and deals at great speed, and can also be used as a plain saw bench. They are made up to 60 in. in diameter.

Machines for cross-cutting with circular saws are shown on

Pl. **40,** Fig. 3, in which the work is brought to the saw, and on Pl. **40,** Fig. 2, which shows the pendulum saw, the method of use of which is obvious. It is seldom advantageous to instal such machines in engineer shops, other than those at base parks.

9. **Cutting speed.**—The correct peripheral speed for circular saws is 9,000 to 11,000 ft. per minute. Saw makers manufacture their saws to run most efficiently at that speed. If a rip saw in good condition be held vertical with the bottom teeth resting on the floor, it will be seen that the rim is still and the centre is loose ; the latter can be pushed and pulled in and out, whilst the former remains stationary. When running at normal speed, the saw becomes stiff throughout, owing to the action of centrifugal force, and the cutting edge is held stiff. If this looseness, or *tension,* were not given, the edge would tend to wobble and cut unevenly. Tension is obtained by hammering, and this process is described in para. 10. If the saw is run under the speed for which it has been tensioned, it may not stiffen and the centre will tend to heat up ; if it is run above the designed speed, the edge will wobble.

10. **Tensioning a saw,** referred to in para. 9, consists in leaving the rim tight and gradually expanding the metal from the rim to the centre by hammering the saw in a series of concentric circles. Opportunities are not likely to occur in the service for sawyers and wood machinists to practise this highly-skilled trade.

Saws will be supplied by the makers already tensioned to run at 10,000 ft. per minute. In course of time, saws will lose their correct tension, owing to friction, heat, and use, and must be sent to the makers for re-hammering.

On active service, if many saws are in use, it will prove economical to enlist specially a saw-hammerer to work at base parks, for the re-tensioning of all saws which have become either damaged or have lost their tension. As a guide to the workshop officer, saws should be re-hammered when (*a*) they appear buckled or (*b*) they have projecting places. Thus, when a saw has a permanent *dish* on one side, or when the rim wobbles when cutting at normal speed (assuming the bench to be running true), or when the centre is obviously tight and the rim wobbles when the saw is held vertically, the bottom teeth resting on the ground, the saw requires re-tensioning.

11. **Power to drive.**—The power required to drive a circular saw of a given diameter will vary with the nature and dampness of the wood, the rate of feed, and the condition of

the saw. Table **M** shows both the size of the cut that can be made with a saw of a given size and the *maximum* power required under normal commercial conditions. If the saw has only rarely to take wood of the maximum size that can be dealt with, the power can be considerably reduced by merely lessening the rate of cutting on such occasions.

TABLE **M**.—*Power required to drive circular saws*

Diameter	Speed	Rip saws			Depth of cut
		Hand feed *	Roller feed *	Rack bench *	
Ins	R.P.M.	H.P.	H.P.	H.P.	Ins.
12	3,200	3	—	—	5
18	2,200	5	—	—	7½
24	1,650	10	15	—	10
30	1,300	12	20	—	13
36	1,100	16	28	—	15
42	920	20	32	—	17
48	820	25	40	32	20
54	700	—	—	40	23
60	600	—	—	48	27
72	500	—	—	55	30

NOTE.—For cross-cut saws take one-half the figures in columns marked *.

12. **Packing a circular saw.**—The object of packing is to keep the saw running steadily whilst cutting, and not, as is sometimes supposed, to warm up the saw to compensate for any inequalities of tension. Provided that the saw is properly tensioned, there is no need to pack it so tightly that friction causes the saw to heat up and expand. The saw should be quite rigid between the packings, which should be so adjusted as to prevent any side play of the saw, but, nevertheless, they should not bind the saw.

Packings, *a* on Pl. **34**, Fig. 5, are placed on each side of the cutting-half of the saw, extending from near the spindle to the bottom gullets of the teeth. Strips of wood, *b* on Pl. **34**, Fig. 6, are screwed a short distance below the level of the table top to support the packings and prevent them being carried away as the saw revolves. Packings are made of a pliable substance, such as gaskine, hemp, old rope, leather, cloth, or felt, the first two being those most usually employed.

The best method of packing is to make two plaited ropes, and to press or hammer them into shape so as to fit the spaces between the saw and the bench; the ends should be tied to prevent fraying. The shaped ropes are then placed one on

each side of the saw, and compressed by means of a pointed stick until just holding the saw (which should then have no perceptible side motion), care being taken to maintain a uniform pressure throughout. The top of the packings must be just below the bench surface.

It is good practice to lubricate the packings with a mixture of thin oil and paraffin, but not with thick oil. The back of the saw does not require to be packed, but it is usually steadied with two pieces of leather, *cc* on Pl. **34**, Fig. **7**, nailed to the wooden pieces, *bb*, about half-way between the spindle and the gullets. Wooden mouthpieces, *dd* (Fig. **5**), should be fitted in the gaps, so that they come up to the packings and prevent them being drawn past the teeth of the saw. Different-sized saws on the same bench will require different mouthpieces.

In the case of badly-tensioned saws a skilled sawyer will be able to adjust his packings so as to generate heat, and make the saw run true. It is not, however, advisable to permit this; the remedy in such cases is to have the saw re-hammered.

It will be obvious that if a thinner or thicker saw is substituted for the one in use, the packings must be replaced or readjusted. Some sawyers keep a pair of packings for each saw they work with.

Saw benches are sometimes met with which are packed by means of leather-tipped set screws; this method is very efficient so long as the saws are in really good condition.

13. **Working circular saws.**—The bearings will require as much attention as those of all high-speed machinery. They are best lubricated with *oil, lubricating, compound* (C. 160, *see* Table **ZA**). Care is required to keep out grit and sawdust. Loose bearings will cause uneven cutting. If bearings, especially that next to the saw, become heated, the heat will be transferred to the saw, and uneven cutting will result. Wood, either in trunk or scantling, should *always be examined for nails before sawing is commenced.*

For sawing straight stuff, first put on the saw, pack it, and arrange the fence so as to come about ½ in. past the teeth; if it is too far past, there is a tendency for the saw to bind and run hot. Next adjust the fence until it is truly parallel with the saw; if it is found difficult to keep the timber up to the fence whilst sawing, adjust the front of the fence 1/16 in. nearer the saw than the back. As timber is pushed through the saw by the sawyer, it should be held well up to the fence by his mate, or puller-through. It should be given a steady feed, *i.e.* as fast as the saw will take. A sharp look-out must be kept for knots and the feed slowed down when cutting through them. For the last 2 ft. or so of the cut, the mate

walks to the other end of the bench and pulls on the wood, whilst the sawyer holds the end to be cut against the fence, finally pushing it into the saw by means of a push stick; working with short stuff, he should push it through from the back with a stick, for safety. In sawing long stuff and thick stuff, small steel wedges should be driven into the cut to open it out and prevent the saw binding. The riving knife, when fitted, will also serve this purpose.

When logs are cut before they have been properly seasoned, the side towards the heart wood tends to bulge and that towards the sap wood to hollow. The sawyer will, therefore, meet with straight timber of section as shown at *a* on Pl. **34**, Fig. 8, straight timber of skew section, timber bent in the direction of its length, and twisted timber.

Pieces like *a* should be sawn by putting the concave side against the fence, which for this purpose should preferably be fitted with ribs, Pl. **34**, Fig. 4. Timber bent in the direction of its length should be sawn with the convex side of the long bend to the fence.

Stuff like *c*, which is convex both sides, can only be properly sawn by making two points of contact on the ribs of the fence.

If it is required to saw small logs, a square batten should be cut first for the log to rest on and so prevent rolling.

In sawing long thick stuff (*e.g.* a piece of 14-in. by 14-in. pitch pine or a thick log) the sawyer and puller-through should be assisted by helpers, who should support the projecting end of the baulk. The helpers should be under the control of the sawyer, and trained not to move the log sideways or to lift it higher than the table. Trolleys, Pl. **36**, Fig. 3, are probably better than men for this purpose, as moving and lifting are avoided.

The following *precautionary measures* should be taken when working circular saws. Use the right hand to take stuff from the right side of the saw and the left hand for stuff on the other side.

In cutting any wood that will take the hand near the saw, use a short stick, with a slot at the end to prevent it from slipping. If it is necessary to hold short stuff in the fence, use a good block of wood instead of the palm of the left hand.

14. **Saw-sharpening machines** are made in two types, viz., hand and automatic. The hand variety only, Pl. **37**, Figs. 1 and 2, will be considered.

It is claimed to be possible completely to gullet and sharpen circular rip, circular cross-cut, and frame saws with the aid of this machine. In the service, however, the gullets and points of the teeth only should be dealt with by machine, the tops of the teeth being finished off with a file. The hand saw-sharpening machine, or, as it should more properly be

named, the hand gulleting machine, is, therefore, complementary to the process described in Sec. **52.**

The machine consists of a hinged and balanced arm, A, carrying the grinding wheel, B. The arm is fitted to a circular swivelling plate, C, an index and pointer being provided to indicate the inclination of the wheel.

In the swivelling arrangement, the hinged arm, A, can have its travel downwards regulated by stops. A spindle, D, adjustable for height and fitted with a nut and washer, serves to hold the saw rigid, and is mounted on a pivoting arm, E, which is also provided with an index and pointer, and is required for putting bevel on the sides of the teeth.

The grinding wheel should run at 5,000 ft. per minute and be of the grade and grit recommended by the makers. Care should be taken that it is not clamped too tightly on the spindle, or else it may disintegrate when running at speed; leather washers should be inserted between the clamps and the wheel to cushion it. The wheel should run absolutely true, and it should revolve with its bottom edge away from the operator, who should wear goggles; it should have a rounded edge, and be $\frac{3}{8}$ in. to $\frac{3}{4}$ in. thick, or one-third the breadth of the gullets.

On the assumption that the saw has already been stoned-down, as described in para. 3, it is then clamped in position, a circular bush is inserted on the spindle of the vice, in order correctly to centre the saw, and the hinged arm, A, of the machine is so adjusted as to bring the face of the grinding wheel parallel to the back of the gullet, which it will enter when A is lowered.

The machine having been set in motion, the operator takes hold of the saw with his left hand and the hinged arm, A, with his right hand. He should then lower the wheel until it is a short distance below the point of the tooth, when the saw is turned round gently until it just touches the side of the wheel. The wheel is first raised to sharpen the point and then lowered to the gullet, and the saw is moved round with the wheel grinding out the gullet to a template, until the back of the tooth is reached. The arm is then raised, and, as the saw continues to revolve, the wheel is allowed lightly to touch the back of the tooth, *but not the top*, which is finished by hand filing, as described in Sec. **52.** Each gullet is dealt with in rotation, care being taken that only light cuts are taken, or the teeth will be heated up and lose their temper. For this reason, if much metal is to be removed, a little from each gullet should be removed at a time, and the saw rotated three or four times.

Gulleting machines can be provided with a vice, Pl. **37,** Fig. 2, for taking pit, cross-cut, hand, and mill frame saws,

and they are then suitable for topping, gulleting, and bevelling.

It will be found that the abrasive wheels will glaze and lose their cutting power after a time; their cutting surface must then be trued up with a diamond dresser or the edge of a file.

54. *Band saws*

1. **Introductory.**—Band sawing machines may be divided into :—

i. Log band saws with a separate log carriage on wheels, for ripping only.
ii. Band re-saws for cutting down slabs into thin boards, with roller feed.
iii. Small machines, using narrow band saws, for cutting intricate shapes, as in patternmaking and some phases of joinery; such saws will require a blade with teeth designed to cut both with and across the grain of the wood.

Of these, (i) and (ii) may be found in permanent military mills and base park workshops, but will not be otherwise used by the military engineer.

A properly qualified saw fitter is required to make these machines run successfully; he should be able to sharpen, set, hammer, tension, and *doctor* the saws. Provided this is done, the conversion of timber by large band saws requires no very great degree of skill on the part of the operator.

All band saws have the advantage over circular saws in that they remove less wood; their relative thinness, however, leads to more frequent damage to their comparatively weak teeth. The principles for sharpening them are the same as those for circular saws. Pl. **34,** Fig. 11, shows typical teeth formed for ripping soft wood.

An automatic sharpening machine is essential for all types of band saws. The teeth are usually spring set, but swage set teeth are effective. Care must be taken that the set on each side is exactly the same, or digging in will result (and, consequently, broken saws).

2. **The chief causes of breakage and trouble with all blades** are as follows :—

i. Running a wide and thick saw too fast over pulleys of small diameter. Correct speeds are given in Tables **N** and **O,** page 225.
ii. Saw pulleys with excessive crown on their faces. This makes tensioning difficult. Modern machines generally have flat pulleys.

iii. Saw pulleys running out of truth or balance. Modern machines are fitted with an adjustable top pulley.

iv. Saw guides incorrectly adjusted. They should steady the saw, without binding on it and so causing it to heat.

v. Allowing the saw to run back on the pulleys until its back touches the guides. This will warm up the back edge, causing case hardening, and probably stretching and cracking on that edge. By adjusting the top pulley, the saw can be made to run well clear of the guides.

vi. Forcing the feed after the saw has become dull.

vii. Working the saw stretched too tightly (particulars of correct tension are given in Table **P**, page 226). When the machines are not working, the bands should not be tightly stretched.

viii. Incorrect tooth outlines, which are too weak to stand up to the work or have sharp corners in the gullets leading to cracks. Shapes for soft wood are given on Pl. **34**, Fig. 11.

ix. Case hardening the teeth, due to excessive heating up whilst grinding.

x. Defective brazing. The joint must be exactly the same thickness as the rest of the saw.

xi. Dust and chips getting between the saw pulley and the saw. A brush should be fitted to prevent this.

xii. Incorrect *tension* of the saw. The centre portion should be loose (made so by judicious hammering or rolling in a special machine) and longer than the two edges, which will be tight when the saw is strained over the pulleys; when this is so, the saw will cut true. Large band saws will require frequent re-tensioning. The *tensioning* of the blade must not be confused with the tension required to stretch it tightly over the pulleys.

3. **Small band saws** may be defined as those working with bands from $\frac{1}{4}$ in. to 2 in. wide.

Pl. **38**, Fig. 1, shows a modern machine. The saw pulleys are faced with rubber tyres cemented to the rim. The top pulley can be adjusted by a screw, so that the saw can be made to run on any portion of the rim. The tension on the saw is obtained by a spiral spring. The handle, A, varies the distance between centres, and enables saws of slightly different lengths to be used; this allows for breakages. A roller guide, B, adjustable for height, takes the thrust of the saw whilst cutting. The saw is guided through a wooden mouthpiece, C, but no packing is used. The table can be tilted for skew cutting. The brush, D, clears away chips from the rim.

EE are guards. It is desirable also to fit wire guards over the top and bottom pulleys. The speed at which the saw can be run without undue breakage depends on the diameter of the saw pulleys and the width of the saws being used.

Table **Q**, page 226, gives a guide to the sizes of saw and speed which can be used on any particular bench. If larger saws than those specified in this table for each bench are used, breakages will surely ensue.

The teeth of small blades will normally be of the shape shown on Pl. **34**, Fig. 9. An angle of 60° is maintained between the back of one tooth and the front of the next. Teeth are sharpened and set in accordance with the principles governing the sharpening of circular saws. Automatic filing machines can be obtained. No bevel should be given to the top or foot of the tooth. If a band has an odd number of teeth, one is left without set. Spring set is used, and very little is required.

The tension at which small saws are run, the size of tooth, &c., are shown in Table **R**, page 226. It is pointed out that the figures given for tension is half the pressure exerted by the spring or weighted lever after the weight of the top pulley and its spindle, bearings, and the bracket to which it is fixed have been deducted. A good sawyer will usually be able to adjust his tension by the feel of the blade.

4. **Repair of broken band saws** is done by brazing or silver soldering. In brazing, the broken ends are filed square, and a scarf is filed on each end the whole width of the saw and two teeth in length. The finished joint must be no thicker than the saw, so the scarfs must be carefully filed, the two extreme ends being brought to a knife edge. The surfaces to be brazed are cleaned by application of a paste of borax and water, which is allowed to dry and is then lightly dusted off so that a little dry borax remains. The two ends are placed together and bound tightly with iron wire, about 23 S.W.G., Pl. **34**, Fig. 10. Great care must be taken to keep the back edge of the saw in a straight line. On the top of the iron wire, fine brazing wire is tightly wound, covering the full length of the joint. The outside is then covered with powdered borax and the joint is ready for brazing, which is done in a field forge or by means of a blow-lamp. The saw is then allowed to cool, the joint is filed absolutely even with the remainder of the saw, and is finally polished with emery.

Pl. **34**, Fig. 12, shows a clamp for brazing band saws. When using this clamp, iron binding wire can be dispensed with. The joint is made in the manner already described, and while still hot it is pressed hard between the faces of the clamp, "a" "a."

To face p. 224]

TYPES OF CIRCULAR SAWS

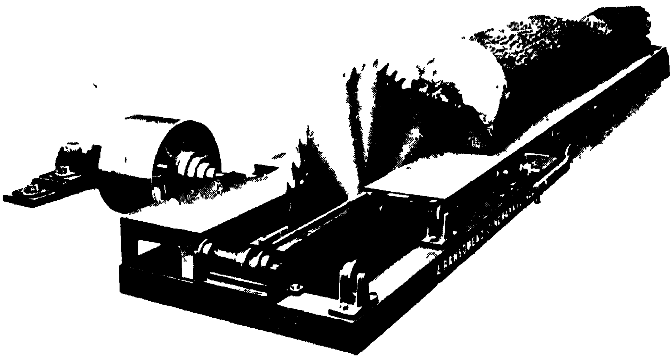


Fig. 1 Rack Bench

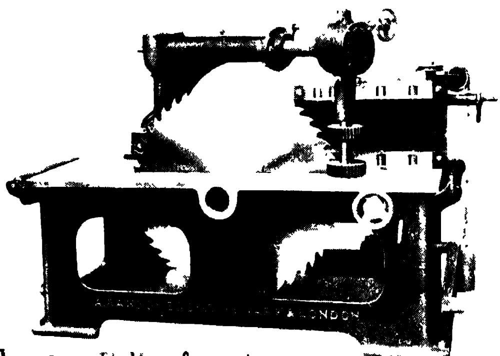


Fig. 2 Roller-feed bench

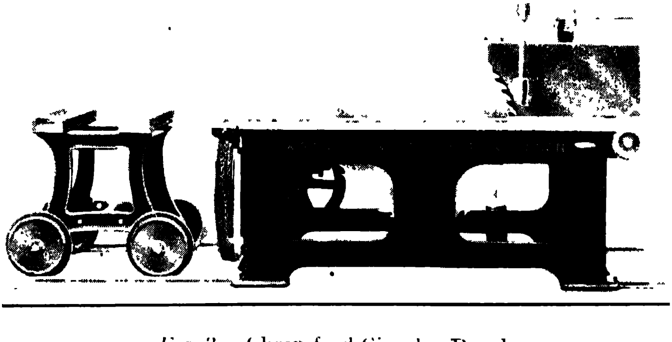


Fig. 3 —Chain-feed Circular Bench.

[*Permission of Messrs. A. Ransome & Co., Ltd.*, 63, *Queen Victoria Street, London, E.C.*4.

SHARPENING MACHINES AND WOODWORKING TOOLS

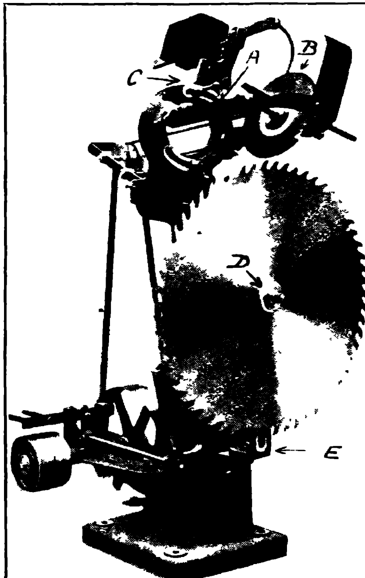


Fig. 1.

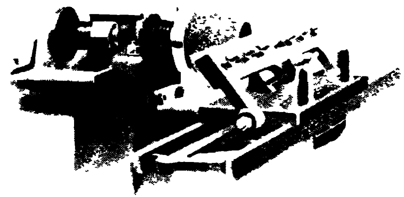


Fig. 1(a).

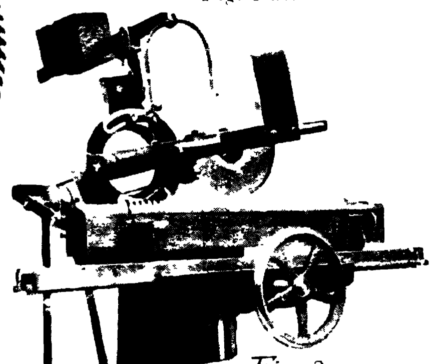


Fig. 2

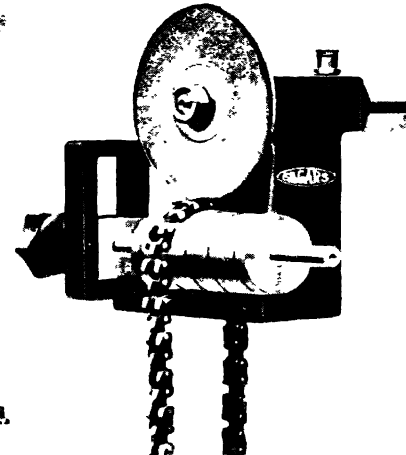


Fig 3.

[Reproduced by permission of Messrs. J. Sagar & Co., Ltd., Canal Works, Halifax.]

BAND SAW AND MORTISING MACHINES

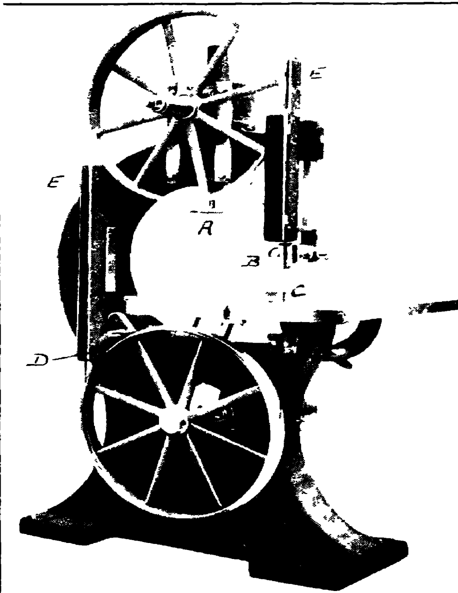


Fig 1.—Band Saw.

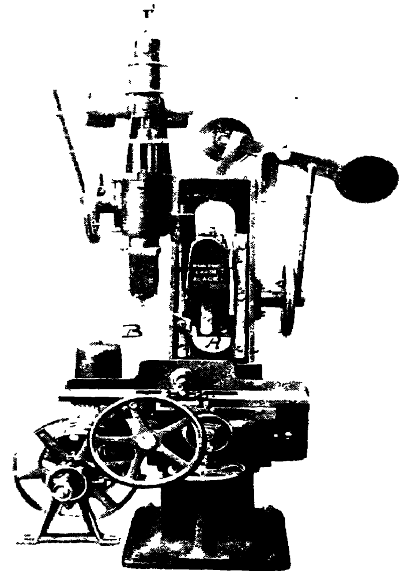


Fig. 2.—Mortising Machine.

[*Permission of Messrs. A. Ransome & Co., Ltd., 63, Queen Victoria Street, London, E.C.4.*]

Plate 39.

VARIETY WOODWORKER AND OVERHAND PLANER

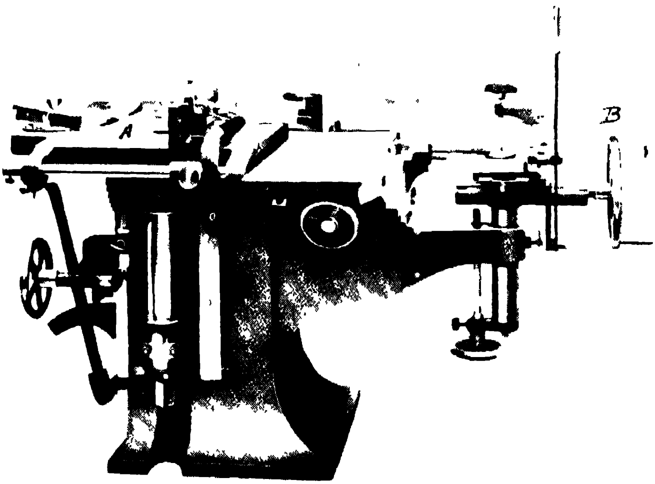


Fig. 1

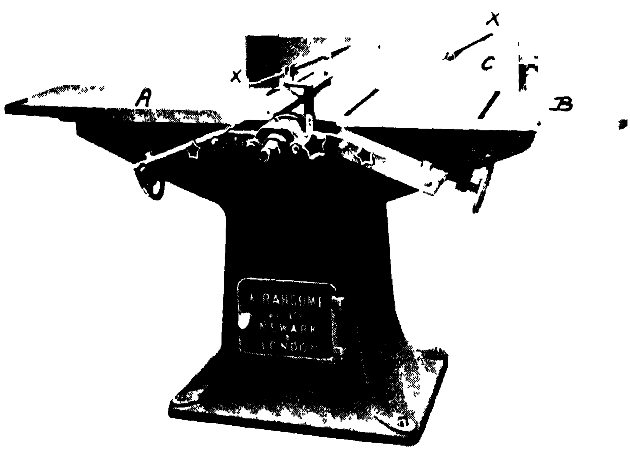


Fig. 2.

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TYPES OF SAWS

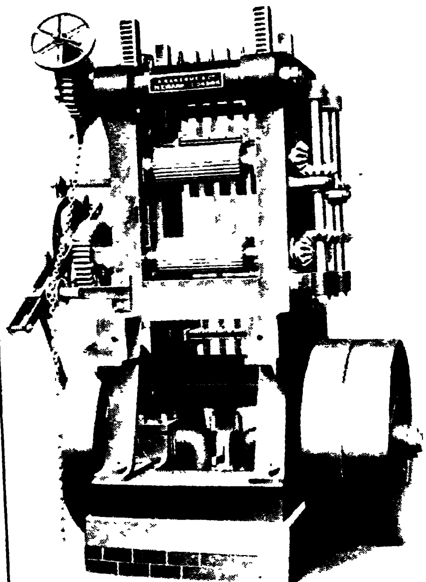


Fig. 1.—Log Frame.

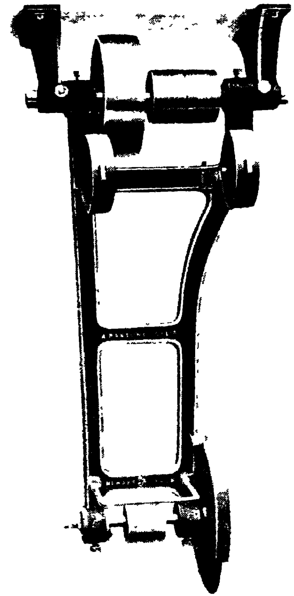


Fig. 2.—Pendulum Saw.

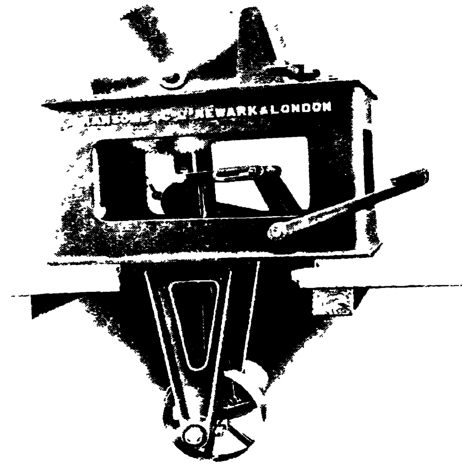


Fig. 3.—Cross-cut Bench.

[illegible] Ransome & Co. Ltd. 63, Queen [illegible] Street, London [illegible]

Electric band-saw brazing machines are now obtainable, which are easier, quicker and cleaner to operate than the blow-lamp type, and they are also safer from a fire risk point of view.

5. **Cracked saws.**—The teeth of band saws will tend to crack at the gullets if the rate of feed is forced when they are dull. Such cracks must be immediately stopped by drilling a small hole in their extremity.

Should any lumps appear on bands, they should immediately be hammered out by a properly qualified saw doctor.

6. **Ordering band saws.**—The following information is required :—

i. Tracing of teeth and width of saw. If tracing cannot be given, state type of wood to be cut.
ii. Gauge of saw.
iii. Length of saw.
iv. If jointed or unjointed.

TABLE N.—*Power required to drive log band saws*

Diameter of saw pulley	Width of saw	Diameter of log	Revs per minute	Machine running light	H.P. cutting maximum
In.	In.	In.		H.P.	
54	5½	36	520	4	45
60	6	36	480	4½	55
60	6½	48	480	4½	60
72	7½	60	400	5½	75
84	9	60	335	7	85

TABLE O.—*Power required to drive band re-saws*

Diameter of saw pulley	Width of saw	Thickness of saw	Revs. per minute	Capacity per minute	H.P. maximum
In.	In.	B.W G.			
48	4	—	550	60 ft. of 11-in. deal ..	28
48	4	—	550	80 ft. „ 7-in. „ ..	16
48	4	–	550	100 ft. „ 7-in. „ ..	20
54	5	18	550	10 ft. „ 16-in. mahogany ..	16
54	5	18	550	18 ft. „ 24-in. mahogany ..	20
54	5	18	550	21 ft. „ 15-in. pine ..	26
54	5	18	550	60 ft. „ 9-in. deal ..	28
60	6	19	575	100 ft. „ 9-in. „ ..	35
60	—	–	575	180 ft. „ 9-in. „ ..	45

TABLE P.—*Tension for large band saw blades*

Width of saw	Thickness of saw in B.W.G.						
	21	20	19	18	17	16	15
In.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.	Lb.
$2\frac{1}{2}$	710	720	840	940	—	—	—
3	840	860	1,000	1,120	—	—	—
$3\frac{1}{2}$	970	1,000	1,180	1,310	—	—	—
4	1,080	1,140	1,340	1,490	1,880	—	—
$4\frac{1}{2}$	1,210	1,280	1,510	1,680	2,110	—	—
5	1,340	1,420	1,670	1,860	2,340	2,580	—
6	1,600	1,700	2,000	2,230	2,800	3,100	3,460
7	—	—	2,275	2,530	3,180	3,530	3,940
8	—	—	2,550	2,830	3,560	3,960	4,420
9	—	—	—	3,130	3,940	4,370	4,950
10	—	—	—	3,430	4,320	4,820	5,680
12	—	—	—	—	—	5,680	6,340

TABLE Q.—*Speed of small band saws*

Diameter of saw pulley	Maximum width of saw	Speed per minute
In.	In.	Ft.
24	$\frac{3}{4}$	3,000
30	$1\frac{1}{2}$	3,500
36	2	4,000 to 4,500
42	$2\frac{1}{2}$	5,000 to 5,500

TABLE R.—*Details of small band saws*

Width of saw	Distance from point to point of saw	Thickness of saw	Maximum tension	Minimum radius of the pattern cut
In.	In.	B.W.G.	Lb.	In.
$\frac{1}{4}$	$\frac{1}{8}$	22	55	$\frac{3}{4}$
$\frac{3}{8}$	$\frac{3}{16}$	21	100	$1\frac{1}{2}$
$\frac{1}{2}$	$\frac{1}{4}$	21	160	$2\frac{1}{4}$
$\frac{5}{8}$	$\frac{1}{4}$	21	200	3
$\frac{3}{4}$	$\frac{5}{16}$	21	240	$4\frac{1}{2}$
$\frac{7}{8}$	$\frac{5}{16}$	21	280	6
1	$\frac{5}{16}$	21	320	8
$1\frac{1}{4}$	$\frac{3}{8}$	20	410	12
$1\frac{1}{2}$	$\frac{7}{16}$	20	525	20
$1\frac{3}{4}$	$\frac{7}{16}$	20	640	24
2	$\frac{1}{2}$	20	755	30
$2\frac{1}{4}$	$\frac{5}{8}$	20	870	36

55. *Log frame saws*

1. The **log frame saw** consists of a reciprocating frame, actuated by a crank. The frame holds any number of saws required, spaced at any interval; therefore, the machine can be used either for breaking down trunks into flitches or for sawing the trunk directly into boards. These machines are comparatively slow cutters, but their use saves labour under certain circumstances. Pl. **40,** Fig. 1, shows a modern type. The saws are strained in the frame and packed top and bottom.

2. The **teeth are sharpened** in a similar way to those of a circular saw. Pl. **34,** Fig. 19, shows a tooth inclined 5° from the vertical, suitable for use when a large number of saws are in use simultaneously. Teeth with a hook of 20° may be used for soft wood where only one or two are used in a frame. The greater the hook, the faster the cutting, but the greater the power required to drive.

3. The centre teeth tend to become more quickly worn than the end teeth. The length of the teeth must, however, be kept absolutely even. In ranging down the teeth prior to sharpening, a file or files are attached to a wood block; the edge of the wood is kept pressed against the side of the saw, and the teeth can then be readily evened up by the file or files.

4. **Power required to drive** is given in Table **S,** below, for oak. For soft wood, take two-thirds of the figures given.

5. **When ordering saws** it is advisable to give :—

i. Length of saw and sketch of attachment.
ii. Tracing of tooth.
iii. Gauge and breadth of tooth.

TABLE **S.**—*Power required to drive log frame saws*

Size of log	Stroke	Revs. per min.	No. of saws in frame	B.H.P.	
				Light	Cut
In.	In		No.		
18	17	200	18	3½	20
24	20	180	24	6	30
30	24	150	30	7	38
36	26	140	36	8	42
42	28	130	42	9	50
46	30	120	48	10	60

NOTE.—Powers required for fewer saws can be readily deduced from these figures.

56. *Woodworking machinery for joinery*

1. **Introductory.**—The variety and nature of woodworking machinery available for special purposes is best appreciated by perusing catalogues. The following machines will be required in permanent service shops producing joinery :—

- i. Machines with cutter knives for planing, thicknessing (*i.e.* planing to a definite thickness), moulding, grooving, and tenoning.
- ii. Machines for mortising.
- iii. Machines for boring.

The machine known as the *General Joiner*, or *Variety Woodworker*, combines the majority of the processes mentioned in (i), (ii), and (iii), and is suitable for small shops where a separate machine for each would not be economically justified. It is shown on Pl. **39**, Fig. 1.

A wood-working lathe and a sandpapering machine are essential in the patternmakers' shop if large production is required.

2. **Cutter-blocks.**—Pl. **34**, Fig. 13, shows the horizontal spindle and circular planing cutter-block of a machine of class (i). The cutters, Pl. **34**, Fig. 20, are made either of iron with a hardened steel edge or entirely of steel, and are fixed in position by the cover and nuts. *Two* cutters are shown in the figure, but three are common. The spindle rotates in ball bearings, and the cutting edges have a speed of 5,000 ft. per minute. For even cutting it is, therefore, essential that the spindle runs absolutely true, and that the cutters are correctly balanced ; the cutters must be of the same weight, shape, and linear dimensions ; they should be fastened to the cutter-block in such a way that their centres of gravity are the same distance from the centre of the spindle.

Square cutter-blocks are sometimes met with, but these are dangerous, and are forbidden by the Home Office regulations to be fitted to planing machines, unless mechanically fed.

3. **The overhand planing machine** is shown on Pl. **39**, Fig. 2, and comprises a horizontal spindle and cutter-block, Pl. **34**, Fig. 13, a rising back, A, a rising front bench, B, and an adjustable canting fence, C. It is suitable for planing, bevelling, and rebating without change of cutters.

In fixing the cutters to the block, place a strip of thick brown paper, about $\frac{3}{4}$ in. wide, between the cutter and the block at the back edge, to cause the cutter to bear firmly in the block at the front edge ; also let the cutting edge project $\frac{1}{32}$ in. past the tips of the block. The cutters must be set

true to the back table, be correctly balanced in the block, and all project equidistantly from the block.

Adjust the back table exactly level with the highest point of the cutters; it will then receive the wood as it is planed. If the back table were lower than the cutters, the planing would be uneven and there would be a dip at the end of each piece of timber planed; if it were higher, planing would be practically impossible. Adjust the front table below the level of the cutters, according to the cut required.

The greatest care must be taken always to use the guard, Pl. **39**, *Fig.* 2, *whilst the machine is in operation. It should never be moved higher than is required to allow the work to pass underneath it.*

A push-stick should invariably be used when short thin stuff is being worked, the necessary pressure being supplied by the springs, XX.

Rebating is done by setting the fence of the machine from the front edge of the table a distance exactly equal to the size of the rebate required, and then lowering the front of the table to the depth required. A deep rebate can be done in two or more operations.

Chamfering can readily be carried out by adjusting the fence to the required cant.

Pl. **39**, Fig. 2, shows the best type of guard for overhand planers.

4. **The thicknessing machine** is a planing machine which consists of a horizontal spindle and cutter-block and a serrated feed roller on spring-supported bearings. The table can be so adjusted that the planed board may be of any required thickness. A pointer on the machine shows the thickness setting for any position of the feed roller. The method of adjusting the cutters is the same as that for the overhand planer (*see* para. 3).

This machine is much safer to work than the overhand planer, but it can be used for planing and moulding on one side only.

5. **The moulding machine,** worked with shaped cutters, Pl. **34**, Fig. 17, attached to square cutter-blocks, Pl. **34**, Fig. 18, may have both vertical and horizontal spindles.

The general joiner, Pl. **39**, Fig. 1, can be adjusted to perform moulding work, the cutter-block for the moulding cutters being fixed to the horizontal spindle on which the circular saw revolves on the plate. *Four-cutter* moulding machines have two vertical and two horizontal spindles, and will perform several separate operations on the faces and sides of a board in one setting. For complicated mouldings, several separate cutters are ground to simple outlines and placed

together; this is better than one long-contoured cutter, as grinding is much easier and a broken cutter can be replaced at less expense.

6. **Grooving** is done by small circular "drunken" saws, or by grooving cutters fixed to a block mounted on the general joiner by means of tilting the bench, A on Pl. **39**, Fig. 1, the depth of groove with a given saw being regulated by the amount of tilt.

7. **Tenoning** may be done by special attachments with rotating cutters, working at about 3,000 feet per minute, on the general joiner, Pl. **39**, Fig. 1. A square-edged cutter, working across the grain, as is necessary in tenoning, would tear the wood at the shoulder. A scribing cut is, therefore, arranged for first, down *aa* on Pl. **34**, Fig. 15, with a cutter, the teeth of which are sharpened by means of an oilstone.

Tenoning can also be done with the grooving saw and tilting-table.

8. **Mortising** can be carried out by machine in the following three ways:—

i. With the mortising bit placed on the spindle of the general joiner, Pl. **39**, Fig. 1, the work being held in the traversing vice, B. With this method the ends of the mortice are round, and require clearing with a hand chisel.

ii. In the machine, Pl. **38**, Fig. 2, which is fitted with a continuous rotating chain cutter, A, which must be run fairly loose.

iii. In the machine, Pl. **38**, Fig. 2, with the hollow chisel with rotating centre, B; the chisel is shown on Pl. **34**, Fig. 16.

Mortising chisels should rotate at about 2,000 revolutions per minute; chain cutters should run at 1,500 to 2,000 ft. per minute. Hand-power mortising machines are also met with.

9. **Preparing and sharpening cutters for wood-working machinery.**—Planing cutters are received from makers already sharpened. To be re-sharpened they are ground on an emery wheel, mounted, as shown on Pl. **37**, Fig. 1 (*a*), with a traversing cutter-holder. For cutting soft woods a bevel of 30° is used, and for hard woods from 40° to 50°. The edge is finished on an oilstone. Care must be taken not to press too hard on the emery wheel or too long on one place, or else the temper will be drawn. It is very important that sets of irons to be used in the same cutter-block should be ground absolutely the same as regards weight, length, breadth, size of bevel, &c., so as to obtain the correct

balance. The balancing machine, Pl. **35**, Fig. 6, should be used to correct their weights. An incorrect balance would cause uneven work and would rapidly wear the bearings of the machine. It is, however, useless to go to this trouble unless the operator arranges the cutters evenly in the block so that balance is obtained. This point should be carefully watched.

Moulding cutters of any required shape can be obtained from makers. Blocks can also be similarly obtained for grinding-up locally. These may have to be softened. They are then filed straight across to the required profile, and the bevel is ground on the emery wheel. The cutter is then hardened and tempered. Where the composition of the steel is unknown, heat to a good cherry-red and temper by the sand-bath or hot-plate method, to give an even colour of brown dappled with purple for moulding cutters, and straw colour for straight planing irons. The service tool steel, No. 3 Temper, is very suitable for cutters.

10. **Sharpening chain cutters** for mortising machines is best carried out with the special fitting, Pl. **37**, Fig. 3. The face angles of the cutters should be ground straight across to 70° for soft wood and 80° for hard wood. The tips are ground without bevel.

11. **Ordering spare cutters, &c.**—The following procedure should be adhered to when preparing orders for spares :—

i. *Plane irons.*
   (*a*) Give length, width, and thickness.
   (*b*) Send template or sketch showing length, width, and position of bolt slots.
   (*c*) Give bevel required, or state whether for hard or soft wood.

ii. *Moulding irons.*
   (*a*) Send sketch or template of section of moulding.
   (*b*) Give position of slots in the cutter and the size of block it is fastened to.
   (*c*) State whether for hard or soft wood.

iii. *Mortice chisels.*
   (*a*) State type of chisel required and for what use.
   (*b*) Send template or exact sketch of socket.
   (*c*) Give width of chisels and length required from socket.
   (*d*) With rotary machines, give exact sketch, or send pattern of cutter, with size of socket.

12. **Exhaust system.**—In permanent woodworking establishments an exhaust system should be installed to

remove the sawdust and chips. A single centrifugal exhaust fan usually deals with the whole requirements in saw mills of moderate size. Dampers must be placed near each machine so that they can be closed when the tools are not working in order to economize in power. Also a grid must be placed in the conduit near the fan inlet to limit the size of chip which can be drawn in.

A saw mill with about 50 H.P. continuous average load requires an exhaust fan taking about 7 H.P.

57. *Safety precautions for woodworking machinery*

1. All woodworking machinery works at very high speeds at the cutting edge, and great care is necessary to prevent accidents to the operators. The safety precautions necessary are laid down in "The Woodworking Machinery Regulations, 1927," authorized by the Factory Act, 1901, and issued by the Home Office.

These regulations are divided into two portions: (*a*) the duties of the occupier, and (*b*) the duties of the persons employed. They may be briefly summarized as follows:—

(*a*) *Duties of the occupier.*

i. Every woodworking machine shall be provided with an efficient stopping and starting device within easy reach of the operator.

ii. Sufficient clear space shall be maintained at every woodworking machine to enable work to be carried on without unnecessary risk.

iii. The floor surrounding every woodworking machine shall be maintained in a good and level condition, and shall not be allowed to become slippery.

iv. Where structural conditions permit, sufficient natural light must be provided at every woodworking machine. Failing this, artificial light must be provided and so fixed or shaded that the direct rays of the light do not fall on the eyes of the operator when working the machine.

v. No woodworking machine shall be operated in an underground room or semi-basement.

vi. The temperature of woodworking shops shall not be less than 50° F.

vii. Men under training are to be instructed as to the dangers arising from woodworking machinery, and the precautions necessary.

viii. Special regulations for individual machines. These are discussed in para. 2.

(*b*) *Duties of persons employed.*

Every person employed in operating machinery shall :—

i. Use and maintain in proper adjustment the guards provided, in accordance with the regulations.

ii. Use " spikes " or " push-sticks " when operating—
Hand-fed circular saws,
Hand-fed planing and thicknessing machines,
Hand-fed vertical spindle moulding machines.

2. Special regulations for individual machines.

(*a*) *Circular saws.*—Every circular saw shall be fenced as follows :—

i. The part of the saw below the bench table shall be protected by two plates of metal or other suitable material, one on each side of the saw. These plates shall be not less than 6 in. apart, and shall extend from the axis of the saw not less than 2 in. beyond the teeth of the saw.

ii. Behind and in a direct line with the saw, a curved riving knife shall be set, of not more than ½ in. greater radius than the largest saw used in the bench, and securely fastened to a bracket or other means of adjustment below the bench.

iii. There shall be fitted a neat close-fitting shield for the top of the saw, flanged as deep as the roots of the saw teeth, and capable of rapid adjustment (preferably by use of a front shield), to cover the front of the saw blade where it is not buried in the wood. A view of the line of the saw can be given by slots in the edge of the front shield.

iv. A suitable push-stick shall be kept available for use at the saw bench, or a " pusher " and " puller " shall be provided.

(*b*) *Band saws.*

i. The spokes of the pulleys shall be effectively enclosed. The lower pulley should be protected by a metal sheet, and the upper pulley by network, so that sight and light may not be obscured.

ii. The saw blade shall be guarded, except between the upper packing and the top of the table.

(*c*) *Overhand planers.*

i. These machines should be fitted with cylindrical cutter blocks and bridge guards.

ii. For short work (*i.e.* under 12 in. long) " push-sticks " or " work holders " are to be provided.

(*d*) *Spindle moulders.*

i. The cutter of every vertical spindle moulding machine shall be, when practicable, provided with the most efficient guard, having regard to the nature of the work being performed.

ii. For such work as cannot be performed with an efficient guard for the cutter, the wood being moulded, shall be, if practicable, held in a jig or holder.

iii. A suitable " spike " or " push-stick " shall be provided for use at every spindle moulding machine.

(*e*) *Mortising machines.*

The chain of every chain mortising machine shall be provided with a guard which shall enclose the cutters as far as practicable.

(*f*) *Feed rollers,* as on planing, thicknessing, and moulding machines, are to be provided with efficient guards, set slightly above the work.

(*g*) *Sandpapering machines* should not be worked without an efficient exhaust and dust collecting apparatus attached.

(*h*) *All belting, shafting, &c.,* within reach of the operator of any woodworking machine is to be securely guarded.

3. **Copies of the Regulations** for Woodworking Machinery, 1927, may be obtained from H.M. Stationery Office. A copy of these Regulations should be posted in a prominent position in every woodworking machinery shop.

Full details of the safety precautions referred to in this Section are contained in Safety Pamphlet No. 8, " Fencing and other Safety Precautions for Woodworking Machinery," issued by the Home Office, and obtainable from H.M. Stationery Office.

For Bibliography, see page 687.

CHAPTER XI

WORKSHOP ECONOMICS

58. *Factory organization generally*

1. It is necessary to distinguish between production shops (*i.e.* factories) and repair workshops.

In peace-time the military engineer will have little to do with factory organization. Stores required in the service, if of commercial pattern, can be produced by civil factories at far cheaper rates than is possible in the case of small shops, on account of the large quantities involved.

If not of commercial pattern, they will be produced either by fostering an industry in civil life, which is sometimes necessary in order to obtain a large production for war, or by manufacture in the National Factories.

2. An army shop may, however, be required to manufacture under two conditions :—

i. In a theatre of war new articles will be devised or invented, and factories may be required to produce a first supply until factories in the United Kingdom can be organized to produce such new stores.

ii. In peace-time it occasionally happens that a few special stores are urgently required in small numbers. In such cases, it is not always economical to entail the cost of preparation of the specifications and drawings essential for a contract. An army shop may be required to produce to sample.

3. Further, although no general system can be enunciated for the economic operation of repair workshops, for each case must be specifically considered, nevertheless, certain fundamental principles will be common to all, and can best be derived from consideration of the systems of factories.

It is, therefore, necessary that the military engineer should study the fundamental principles of factory organization and accountancy with a view to grasping the reasons for the methods adopted.

4. The objectives of any factory are to produce :—

i. Articles of a given general type, of a standard equal to that specified.
ii. In maximum possible quantities.
iii. At minimum possible cost for each article.

5. In order to attain the objective in para. 4 (i), factories are designed to produce certain categories of articles. So far as possible the lay-out is specifically designed to manufacture to certain definite specifications (*see* para. 10). In design and specification it is too frequently the ambition of British factories to produce the best possible article, regardless of the fact that the Public may, rightly, prefer a cheaper article, which will do what is required, but no more. In other cases, the buyer may have his own ideas as to the design best suited to his requirements. In such cases the manufacturer must decide whether it will pay him, directly or indirectly, to alter his designs, and perhaps factory lay-out, in order to accommodate his customers.

In general, he will endeavour to produce a good article in quantity and to educate the Public to use it. Clearly this involves a sales branch with a system of advertisement which must *sense* the public taste on the one hand, educate the Public on the other, and act in close touch with the designs branch.

An army factory in a theatre of war will to some extent be faced with similar problems, but can demand of superior authority that decisions be made as regards design and that standard designs be adopted for all consumers.

6. As regards the objective in para. 4 (ii), it is necessary to realize that the cost of an article consists fundamentally of two component parts :—

i. Direct charges, *i.e.* labour and material.

ii. Indirect charges, viz. supervision, cost of power supply, depreciation and other *standing* charges, cost of designs and sales branch, general office expenses, and other administrative charges.

It will be sufficiently obvious, without detailed argument, that the indirect charges will not increase proportionally to the quantities of any one article produced.

An increase of the output of a given article will, therefore, reduce the total cost of the unit article.

Such increase will be sought by the methods referred to in para. 5.

An army factory will be concerned in reducing the number of types demanded of it, and is unlikely to be troubled with insufficient average demand for any one standard type. But it is more liable than a civilian factory to troubles arising from an uneven demand. These must be met by predicting average demand, and manufacturing for stock, with the object of creating sufficient reserves to meet heavy seasonal demands.

Manufacture against indent is the death-knell of efficiency.

7. In respect of the objective in para. 4 (iii), when due attention has been given to the principles inculcated in paras. 5 and 6, it should be found that 70 per cent. at least of the aggregate gross costs of the factory are due to direct charges. In a really well-organized business direct charges may even be as much as 80 per cent. of the aggregate cost. In consequence, the principal administrative effort will be directed to possible reductions in direct costs.

8. As regards material, it is necessary to study :—

i. *Initial cost.* A purchase branch is required, charged with the duty of watching market fluctuations of raw material and endeavouring to purchase at cheap periods, of obtaining material of good enough, but not unnecessarily good, quality, and of suggesting use of cheaper materials in lieu of those which are expensive.

ii. *On-costs,* such as freight, handling charges, and store branch administrative charges. The on-cost if not carefully watched may add a considerable percentage to direct cost of stores. This will be generally the duty of the stores branch.

iii. *Waste of material.* Clearly all material issued is not embodied in the final article ; but wastage, *e.g.* turnings, filings, timber ends, and sawdust, must be reduced to a minimum, and such wastage has a value of its own as a by-product.

An undue proportion of waste will usually be revealed by careful scrutiny of cost accounts (*see* para. 12).

iv. *Possible reduction of material in the finished article.* This is primarily a matter for the designs branch. As an example, consider the reduction of four nails per slat in a trench board to three nails ; in France in 1918 this resulted in an economy of about 40 tons of nails a month—say, £1,000 at prevailing prices.

9. As regards labour, reduction of cost will lie in the reduction of manual operations to a minimum :—

i. The management must consider to what extent automatic machinery can be used to replace manual labour.

ii. *Labour motion* demands study.

iii. The number of *operations* by skilled artisans is often reducible.

iv. The British artisan's nature tends towards an unnecessarily high standard of finish, *e.g.* use of wrought timber for packing cases, to quote an extreme case.

v. Material must be *fed in* with the minimum of handling and *carry*.

As some loss both of labour and material is inevitable owing to *rejects*, it is very desirable to organize inspection during manufacture, so that faults, which would involve rejection of the completed article, may be detected at the earliest possible stage.

10. As the highest development of such an organization, the mass production factory is the ideal. In this case the factory can be laid out and equipped with a special view to the factors referred to in para. 9 (ii), (iii), and (v).

There are four main principles to be observed in the lay-out of a factory or workshop :—

i. All departments should be under one roof.

ii. All shops should be on the same level.

iii. A continuous flow of work through successive departments should be allowed for.

iv. Transport should be by trolleys on a hard floor when possible, and not by tramway.

More often a factory is designed to produce a certain number of definite standard articles at a given average rate a month. Even in such factories the alteration of a design will usually cause complete paralysis of at least a section of the factory for a considerable period—usually from one to two months, but conceivably for a considerably longer period.

It is the duty of an officer i/c workshops to invite attention to the effect of any proposed change of design after he has carefully estimated that effect. Responsibility for any consequent loss will then rest with the superior authority who overruled him.

11. The studies inculcated in paras. 5 to 9 cannot be given effect to without accurate statistics.

A manager, with statistics before him not only of the last month or quarter but of preceding periods with which he may institute comparisons, will, in the first place, consider broadly the proportions of direct and indirect charges.

Let it be supposed that these are 70 per cent. and 30 per

cent. respectively. He will be endeavouring constantly to reduce the 30 per cent. for indirect charges; whilst so doing, he must bear in mind that an over-meticulous system of administration may defeat its own object in either of two ways :—

i. It may involve so large a staff for its operation as to cost more than any economy it can reveal as possible.
ii. It may result in such a mass of figures as to conceal, rather than reveal, waste.

12. Apart from this study of indirect expenditure, the manager will be more concerned with the possibility of reducing the direct costs by the methods referred to in paras. 8 and 9. For this purpose he will have before him statistics which reveal a proportion between labour and material. Let it be supposed that this has normally stood at 52 per cent. for labour and 48 per cent. for material. Next suppose the account for this last period shows this proportion to have altered to 54 per cent. and 46 per cent. Is this alteration due to an economy in material (result of some particular effort)? Or is it due to waste of labour? The manager will decide having regard to the total cost per article, *i.e.* whether reduced or increased, and act accordingly. He will, generally, be endeavouring to alter this proportion by effecting economies in labour and material alternately. The cost account will reveal the effect of his efforts.

13. In an army workshop in peace-time it will usually be the case that the shop has a value for the purposes of training soldiers in the duties of their corps. If, therefore, the shop appears from its accounts to be unremunerative, *i.e.* to be producing only at a somewhat higher cost than the work could be done by civilian contract, before deciding to close down the shop it will be necessary that higher authority shall consider whether the apparent *loss* is justified by the training afforded, or whether such training can be obtained by cheaper methods.

59. *Cost accounts*

1. A cost account will, therefore, be devised primarily to exhibit expenditure under certain main headings, *e.g.*—

Administrative charges	}	Indirect charges.
Standing charges	}	
Power supply charges	}	
Operating charges	..	Direct charges.

The total expenditure under each such head will be worked out as a percentage of the whole expenditure.

Let it be assumed that the proportion of one of these main heads has risen above the normal; say that the cost of

the supply of power has risen from a normal 5 per cent. to 6 per cent. in the last period, and that the factory generates its own power.

2. Clearly the manager will require further details, to which end subdivisions of the main heads of the cost account will be required; this main head may be envisaged as subdivided into :—

Labour (engine drivers, &c.).
Fuel.
Oil and waste.
Repairs.

These are also worked out as percentages of the whole.

Comparison with previous accounts may at once reveal, that the fuel bill has increased out of proportion to other items.

This may be due :—

i. To rise in cost of fuel, which will demand an explanation from the purchase branch.
ii. To increased consumption per **H.P.** hour or per **kW** hour ; this will demand investigation as to whether it arises from inefficient stoking or from an inefficiency in the plant (*e.g.* new piston rings may be required).

3. The nature and scope of the factory must decide what headings and sub-headings are required. It must be repeated that an over-meticulous analysis may defeat its own purpose. The accountant naturally tends towards over-doing the account. The engineer is apt to trust too much to inspection and too little to the proper use of his cost account.

It must be realized that inspection should in theory operate in time to prevent waste. A cost account reveals waste and thus acts as a check on inspection. But, on the other hand, a cost account, unless it is used, to a greater extent than will normally be possible, comparatively with cost accounts of similar factories, will not usually suggest improvements in manufacturing systems, as, for example, the possible financial advantage of the installation of some newer type of machine.

The military engineer is beginning to realize the value of cost accountancy. It may be of use to utter a warning against permitting an invaluable servant to become his master.

4. In an army shop the data upon which a cost account is based will be obtained as laid down in the relevant Regulations. The whole system depends on the issue of a *"works order" for every job carried out.*

Stores will be costed against the works order.

Labour will be booked up by foremen or time-keepers and allocated to appropriate works orders.

Indirect charges may be raised by charges from other departments for supply of transport, power, water, light, and perhaps for repairs.

Depreciation will be charged on the plant and equipment and Class A stores as laid down in regulations.

5. **Depreciation** is one of the most complex problems of cost accountancy. It has been defined as *invisible consumption*. The question which always arises is whether a given repair or replacement is chargeable separately as a repair to the cost of operation or treated as an appreciation of an asset.

The renewal of a piston ring is clearly a repair, for it does not actually prolong the life of the engine.

On the other hand, the renewal of a boiler is clearly a proper charge to an asset account.

But between these extremes will arise many debatable questions (*e.g.* renewal of a cylinder). The management or directors who prefer *conservative finance* will usually charge such doubtful renewals to the *operating account*.

60. *Repair workshops*

1. It will be realized from the above that it is difficult to apply the principles of economic factory organization, of which the ideal is mass production, to large repair shops, nor will the cost accounts be of equal assistance.

But here again, the principle of standardizing jobs must be adopted to the maximum possible extent. Again, it is absolutely detrimental to economy and efficiency to demand priority for the repair of any one specific article, *i.e.* a workshop should not be required to effect urgent repairs to *Lorry No.* 1680: it should not be expected to work against such specific requisitions. On the other hand, it must be prepared to assign priority to repair a class of stores. It may properly be told that the supply of lorries of X type is low and priority must be given to the production of this type by the repair of all such damaged lorries awaiting repair.

It will be seen from para. 4 that there is a considerable difference between such orders.

2. The army repair workshop has to some extent a distinct advantage over similar civilian repair shops, *e.g.* a repair motor-car garage; for it may be assumed that, in war, the types of any class of equipment will be reasonably few in number and will be standardized.

Damaged articles received at base repair shops will mostly

require repairs which cannot be effected by the renewal of any ordinary part. They will also be received in considerable numbers of each type.

3. The processes suggested are, therefore :—

i. Sort out articles to definite areas set aside for each type.
ii. Inspection, to classify as *repairable* or *scrap to be broken up for component parts.*
iii. Repair.
iv. Inspection by the inspector of provision branch.
v. Transfer to store depot for re-issue when required.

4. Inspection to classify as repairable or otherwise will demand considerable knowledge of the shop situation. Normally, it will not be possible to do much *manufacture.* Under conditions of pressure it will be advisable to be somewhat ruthless ; the *scrapped* articles will constitute a *quarry* for spares for the *repairable* articles. But too much ruthlessness may result in an unnecessary over-accumulation of components and a shortage in the store depot of serviceable articles. Again, if by chance the shop is slack, repairs may be undertaken which at other times would be inadvisable. On the other hand, an over-accumulation of components may be thankfully received at home depots.

Whilst, then, good judgment is necessary, it is essential to get rid of any idea that 100 serviceable articles must be obtained, much less can economically be obtained, from 100 damaged articles.

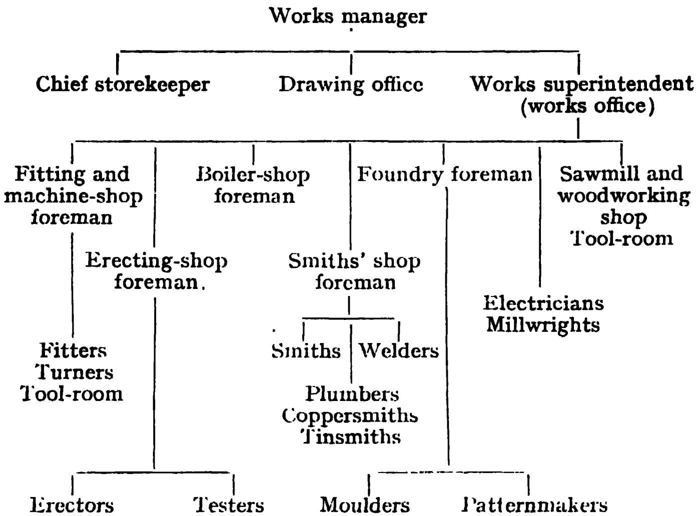
5. **Repairs** will, therefore, consist fundamentally of dismantling, replacement of some damaged component by a serviceable component from the spare part store or from a *scrapped* article, and re-erection.

6. The repair shop is a source of provision to the store depot. Repaired articles must, therefore, be passed as serviceable by independent inspectors.

7. For such work, cost accounts can do little more than reveal that so many articles have been produced by the repair shop at such and such a cost as compared with such and such a cost of an equal number of new articles delivered from home *free alongside wharf.* Expenditure on cost accounts must, therefore, be reduced to what is required to produce such information.

Wrecks brought in for repair, whether classified as *scrap* to be broken up for components or as *repairable*, will be debited to the cost account of the shop at a fixed percentage of the original value, determined by financial authority.

8. General system.—The following diagram shows the organization of a small general engineering workshop :—



This organization can easily be adapted to meet army needs ; for example, a company is ordered to take over and run a civil shop.

The O.C. company becomes the works manager, *i.e.* the executive head of the shop.

The *chain of command* in a civilian engineering works is very similar to the *chain of command* in the army, and, therefore, the taking over by the army in war of small civilian works should present no great difficulties as far as organization is concerned.

The chief point to note in the skeleton organization is that the chief storekeeper is directly under the works manager. This is an obvious precaution, since workshop stores, tools, &c., require careful guarding and accountancy, and no work can be done without stores. The works manager is responsible for all tools, material, &c., in the works, and must be in direct control of the subordinate he has put in charge of his stores.

The patternmaker is shown as working under the foundry foreman. This is usually the case in small works where there are not enough patternmakers to warrant the employment of a foreman patternmaker. Patternmakers, although they work in wood, should never be placed under the orders of the sawyer or carpenter foreman.

9. Works orders.—The object of all clerical work in connection with actual jobs as they pass through a shop is

broadly to prevent the undertaking of unauthorized work, and to enable authorized work to be checked, located, and priced.

All orders for new work and for repairs are dealt with in the works manager's office, where decisions are made as to what new work can be accepted, what repairs carried out, and in what order each job shall be done. *In a small shop, no work of any kind should be undertaken without having been approved by the works manager.* In large shops, power to authorize work up to certain limits can be advantageously delegated to other officers.

Directly a job of any kind is approved in the works manager's office, it is given a distinguishing letter and number, and entered in the Works Order Book. The headings of this book are shown on the following page.

A job having been approved and entered in the Works Order Book, some means must be employed to issue orders to the persons concerned in the execution of the work, and to inform the officer asking for the job to be done that it has been approved.

It is not intended to enter into the details of the clerical system required; these will be found in the appropriate regulations or may have to be developed according to requirements.

10. **Labour.**—It should be possible, by priced requisitions received from the stores, for the costing clerk to find the price of all material used on any one job. Another point is the cost of labour.

A record of this must be kept, or the cost of the finished article cannot be arrived at. Such a record is kept in large shops by means of time cards. Each employee is given some form of time card on which he has to record the time he spends in the works, and how such time is expended.

Men, however, have a tendency not to enter their own time accurately, and the *clock* system is, therefore, usually installed in all large works. In this system, each workman as he enters or leaves the shop drops a card, on which is written his name and the job on which he is working, into a slot connected with a clock; a lever is then depressed by the workman, a bell rings, and the actual time the owner of the card *clocks in* or *clocks out* is recorded on his card.

Cards are of sufficient length to contain a weekly record, while special spaces are provided for overtime. At the end of the week they are handed in to the timekeeper, who retains the used cards and issues fresh ones.

By some method of this kind the amount of work put in by each man on any particular job can be abstracted, and all jobs can be costed.

Job No.	Work commenced (date)	Work completed (date)	For whom executed	Specification No.	Labour	Material	Overhead charges	Total	Account rendered (date)	Cash received (date)	Remarks
					£	£	£	£			

In small military shops it will not, as a rule, pay to put in the clock system. An accurate enough system for small establishments can be worked by the shop foreman. It will be his duty to keep a record of what each man in his shop does each day.

The costing clerk can then find out exactly what are the direct charges for any particular job.

Elaborations, such as progress boards showing the position of every job as it goes through the shops by means of moving coloured or numbered pegs, can easily be worked out. Such systems are sometimes of great value in preventing small jobs from being overlooked and so delayed, or lost sight of altogether.

There are many and obvious advantages in having some simple system whereby all the direct costs are allocated to different jobs. To begin with, it is possible to find out how many men in the shops are working unproductively.

Suppose 100 sapper tradesmen are employed for six nominal 8-hour days in some military shop. Then at the end of the week it should be possible to find out how the week's 4,800 working hours have been spent. It will be found, however, that tradesmen have been taken for other duties, have arrived late at the works, &c. ; but by means of a system such labour leakage can easily be discovered.

Again, by costing direct charges to different articles, it is possible to find out faults in shop organization, &c. For example, a small article is ordered, but, when made, the direct cost is found to be out of all proportion to its value. Costing will show whether too much has been spent on labour or too much on material. Investigations on these lines will almost certainly show up any flaws in the works organization.

Finally, all jobs under the costing system must have some identification mark or number. All authorized jobs will, therefore, be recorded. Unauthorized jobs are easy to detect, since they will have no Works Order number. Frequent checking of work in progress with the Works Orders has the effect of paralysing unauthorized work.

11. **Hand tools.**—In army shops they are normally issued on loan :—

i. To individual workmen.

ii. In the case of special tools to the foreman of the shop.

It is often better, especially in the case of large shops, to issue all requisite tools to the shop foreman, who will re-issue them daily as necessary. To do this properly he must be provided with a lock-up tool-room and a storekeeper.

In either case it is necessary for the storekeeper or the foreman to keep two card indexes :—

(*a*) An index by tools, which will show on each tool card the distribution of the tools ; behind them are placed the workmen's receipts. This enables stocktaking checks to be made.

(*b*) An index of workmen showing on each workman's card what tools he has on loan. This enables an auditor to check any workman's tool kit. If the workman is transferred from the shop it enables a check to be taken at once of the kit handed in.

Procedure in the case of deficiencies is laid down in Regulations.

PART II.—HEAT ENGINES

CHAPTER XII

THERMODYNAMICS OF THE I.C. ENGINE

61. *Fuels*

1. The heat value of a fuel is expressed by the number of British Thermal Units (B.Th.U.) generated by the combustion of 1 lb. of the fuel.

(B.Th.U. = 778 ft.-lb.)

For acceptance testing, in the case of heavy oil engines the fuel consumption is based on the use of fuel oil having a gross calorific value of 19,350 B.Th.U. (in accordance with the British Standard Specifications).

2. When considering the thermal efficiency of an engine it is necessary to distinguish between the *gross* (higher) and the *net* (lower) heat (or calorific) value of the fuel.

The *gross* value which is that measured by a calorimeter in the ordinary way, is not all usefully employed in the engine. Approximately 9 lb. of steam are formed by the combustion of 1 lb. of hydrogen content in a fuel. The total heat of this steam varies very little over the working range of temperatures usual in engines, contributes practically nothing to the mean effective pressure and is almost entirely lost in the exhaust. It is, therefore, usual to deduct the heat units lost in this way from the *gross* heat value and to call the remainder the *net* heat value.

For example, suppose a particular fuel oil has a hydrogen content of 11·5 per cent., and a gross calorific value of 19,500 B.Th.U. The total heat of steam at 14·7 lb./sq. inch = 1,151 B.Th.U. per lb. (*See* Table V.) Therefore $1{,}151 \times 9 = 10{,}359$ B.Th.U. are lost in the exhaust for every pound of hydrogen burned.

One pound of the fuel in our example contains 0·115 lb. of hydrogen, and the steam heat loss is consequently $10{,}359 \times 0{\cdot}115 = 1{,}190$ B.Th.U. per lb. of fuel.

Therefore the *net heat value* $= 19{,}500 - 1{,}190$
$= 18{,}310$ B.Th.U. per lb.

Manufacturers' published figures for Thermal Efficiency are usually based upon the net (lower) heat value of the fuel, but the *International standard* is based upon the *gross* heat

value, and this was recommended for adoption by the *Heat Engine Trials Committee's Report* (1927). If an engine consumes 0·4 lb. of the oil referred to above per B.H.P. hour at full load, the full load Brake Thermal Efficiencies will be

(1) *Based upon the higher heat value.*

$$\frac{33{,}000 \times 60}{19{,}500 \times 0{\cdot}4 \times 778} = 32{\cdot}6 \text{ per cent.}$$

(2) *Based upon the lower heat value.*

$$\frac{33{,}000 \times 60}{18{,}310 \times 0{\cdot}4 \times 778} = 34{\cdot}7 \text{ per cent.}$$

3. The fuel consumption should always be measured *by weight.* In the first place, measurement by volume is not likely to be so accurate, and secondly, the determination of the S.G. may result in further inaccuracy.

There is a British Standard Specification (No. 209) for heavy fuel oils, which are therein sub-divided into four grades, Nos. 1, 2, 3 and 4, Nos. 1 and 2 having a *minimum* gross calorific value of 19,000, No. 3 of 18,750 and No. 4 of 18,500.

The *flash point* specified is not less than 150° F. (Admiralty demand 175° F.). For requirements as to viscosity, fluidity, &c., reference must be made to the Specification.

Particulars of fuels are given in Table **T.**

62. *Explosive mixtures*

1. It will be understood that to enable the heat energy of a liquid fuel to be converted into mechanical energy in an I.C. engine, it is necessary first to convert the liquid into vapour.

2. **Explosion.**—When an inflammable gas, such as oil vapour, is mixed with oxygen in certain proportions, the mixture will be explosive ; a flame approached to even a small volume contained in a vessel open to the air will cause a sharp explosion. Variations of the proportions will cause changes in the sharpness of the explosion. There is a point where the mixture is most explosive ; at that point the inflammable gas and oxygen are present in the quantities requisite for complete combination. Such a mixture may be called the true explosive mixture.

A mixture of 1 part oil vapour to 14 parts air (by weight) forms a true explosive mixture, but mixtures of from 1 : 10 to 1 : 17 are also easily ignited.

3. When very weak or strong, such mixtures burn comparatively slowly, and a point is arrived at where the mixture is so weak in inflammable gas that it cannot be ignited at ordinary atmospheric pressures and temperatures.

4. If a mixture, which is so weak that it cannot be made

TABLE T.—*Particulars of fuels used in I.C. engines*

	Derived from	Service Nomenclature	Gross heat value B.Th.U.	S.G. at 60° F.	Flash point
			per lb.		
Petrol	Crude petroleum.	Petrol (3 grades).	18,500 to 19,500	0·69 to 0·74	14° F.
Paraffin (kerosene)	do.	Oil, fuel, for oil engines.	18,500 to 19,500	0·80 to 0·85	75° F. to 100° F.
Gas oil	do.	Gas oil	19,000 to 19,500	0·86 to 0·89	150° F.
Heavy fuel oil (residual oils).	do.	Oil, fuel, for heavy oil engines.	18,000 to 20,000	0·9 to 0·98	175° F.
Benzol	Coal	—	17,800	0·88	—
Alcohol	Vegetation	—	11,000	0·82	—
		Average gross heat value of other fuels			
Welsh steam coal	—	—	15,500	(average)	—
Anthracite coal	—	—	14,700	(average)	—
Bituminous coal	—	—	13,500	(average)	—
Town gas ..	—	—	16,000 to 19,500	(500–600 per cu. ft. at N.T.P.).	—
Producer gas ..	—	—	2,080 to 2,400	(130–150 per cu. ft. at N.T.P.).	—
Carbon	—	—	14,500	—	—
Hydrogen ..	—	—	61,500	(344 per cu. ft. at N.T.P.).	—

to explode in an open vessel, is either compressed or has its temperature raised, it can then be made to explode.

5. If inert gases, such as nitrogen, or products of combustion, are mixed with explosive mixtures, such mixtures tend to become less explosive, until such a point of dilution is reached that they will not explode. Here again, by increasing their pressure and temperature, such mixtures may be made explosive.

6. In the foregoing remarks it has been assumed that explosion is started by means of some hot agency, such as an electric spark, or a piece of heated metal. In such cases,

explosion (*which is only very rapid burning*) will commence at the point where the hot agency is applied, and the flame will spread to other parts of the explosive mixture. The time taken to complete combustion will depend on the following :—

i. The nature of the fuel (benzol burns more slowly than petrol).
ii. The explosiveness or proportioning of the mixture.
iii. The degree of turbulence of the mixture. If the explosive mixture were completely stagnant at the time of ignition, the flame would spread so slowly that even in a comparatively slow-speed engine barely half of a correctly proportioned mixture would be burnt before the exhaust valve opened. Rapid mechanical agitation of a charge has the effect of speeding up the explosion to such a great extent that with its aid a correct mixture can complete combustion in the highest speed engines before the piston has had time to travel far.
iv. The proportion of inert gases mixed therewith.
v. The pressure.
vi. The temperature.
vii. The place at which ignition starts. If the explosive mixture is contained in a simple cylinder, it will take a shorter time for explosion to be completed when ignition is at the centre of the cylinder than if it were at one side, as the flame has a smaller distance to travel in the former case.

7. **Detonation.**—This phenomenon is imperfectly understood. One explanation is that when an explosive mixture is ignited the flame travels in the form of a sphere expanding outwards at a very high speed. This motion compresses the unburnt mixture and causes its temperature to increase very rapidly. Two simultaneous processes are involved; the flame is trying to reach the unburnt mixture and a pressure wave is causing the temperature of the mixture to increase. If the rate of increase of temperature at any point is sufficiently great to cause *spontaneous ignition* of the mixture before the flame can reach it, a pressure wave is set up which travels at great speed and strikes the cylinder wall with a sharp ringing sound. In severe cases the cylinder may be fractured.

The spontaneous ignition temperature for petrol and paraffin is about 500° F. For benzol it is somewhat higher.

The higher the compression pressure when ignition takes place the greater the probability of detonation, and therefore

the following values must not be exceeded for the fuels stated :—

Paraffin	.. ..	60– 80 lb./sq. inch.
Petrol ..	.. ..	90–110 ,,
Benzol	.. ..	200 ,,

Two other phenomena must be distinguished from detonation, viz. : *pre-ignition* and *pinking*.

8. **Pre-ignition,** as its name implies, means the commencement of an ordinary explosion too soon in a cycle of operations.

9. **Pinking** occurs after ignition, usually when the engine is heavily loaded and running slowly.

If sufficient time elapses between compression and combustion, some form of chemical action appears to take place in the mixture and the rate of flame propagation is then greater than normal. This is evidenced by *pinking*, which is a much milder phenomenon than detonation. If allowed to go on pinking will result in pre-ignition due to the excessive temperature rise which ensues.

63. *The laws of gases*

1. In an I.C. engine, as its name implies, an explosive mixture is ignited in the cylinder and the temperature thereby increased by the combustion of the gas or oil vapour. The consequent increase of pressure is utilized to push forward the piston.

As pointed out above, a minimum of 14 parts of air are required for the complete combustion of 1 part of oil vapour and therefore the *working substance* is mostly *air*.

An I.C. engine may, therefore, be considered as an *air engine* in which the air is heated inside the cylinder at the commencement of the working stroke.

2. The principal laws of gases are summarized below. For further particulars reference must be made to standard text books on physics.

Specific heat of a perfect gas at constant pressure (per lb.) $= K_p = 0{\cdot}2375$ B.Th.U.
$= 184{\cdot}8$ ft.-lb.

Specific heat of a perfect gas at constant volume (per lb.) $= K_v = 0{\cdot}1691$ B.Th.U.
$= 131{\cdot}6$ ft.-lb.

Ratio of specific heats. $n = \dfrac{K_p}{K_v} = \dfrac{0{\cdot}2375}{0{\cdot}1691} = 1{\cdot}404.$

(1·4 is near enough for calculations).

Difference between specific heats. $= R = 0{\cdot}2375 - 0{\cdot}1691$
$= 0{\cdot}0684$ B.Th.U. $\doteqdot 53{\cdot}2$ ft.-lb.

In the following formula :—

P = pressure in lb./*sq. foot.*
V = Volume in *cubic feet.*
T = Absolute Temp. on *Faht.* scale.
= Temp. in deg. Faht. + 459.

General equation.—Any change of conditions of a gas may be expressed by the formula :

(1) PV^n = constant

in which the index n has some value between the limits 1 (isothermal change) and 1·404 (adiabatic change).

(2) *Work done by a gas on expansion.*

(*a*) *When n is greater than* 1.

$$W = \frac{P_1V_1 - P_2V_2}{n-1} = \frac{53{\cdot}2\,(T_1 - T_2)}{n-1} \text{ foot-lb. per lb. of gas.}$$

(*b*) *When n* = 1. $W = P_1V_1 \log_e \frac{V_2}{V_1}$ foot-lb. per lb. of gas.

$P_1\ V_1\ T_1$ being initial and $P_2\ V_2\ T_2$ final values.

Conversely if the gas is compressed the same amount of work is done *on* the gas between the same limits of pressure, volume and temperature.

(3) *Constant heat content. Adiabatic change* (*see also* Sec. **64**, para. 4).—When there is no loss or gain of heat the change in internal energy of a gas equals the mechanical work done *by* the gas in expanding or *on* the gas in being compressed. This is known as *adiabatic* change for which the index n = 1·404 (1·4 is quite near enough for practical purposes).

$$PV^{1\cdot4} = \text{constant.}$$

(4) *Constant temperature. Isothermal change.*

$$PV = \text{constant. (Boyle's Law.)}$$

(5) *Constant pressure.* $\frac{V_1}{V_2} = \frac{T_1}{T_2}$ (Charles' Law.)

(6) *Constant volume.* $\frac{P_1}{P_2} = \frac{T_1}{T_2}$ (Law of Pressures.)

These three formulæ are combined and concisely expressed by the *characteristic equation for a perfect gas, viz.*—

(7) PV = RT. For 1 lb. of gas PV = 53·2T.

All the above formulæ apply strictly to perfect gases only, but air and the usual explosive mixtures obey the same laws sufficiently closely for practical purposes.

64. *Cycles of operation*

1. **The Otto (constant volume) cycle.**—An internal combustion engine designed for refined mineral oil, such as paraffin, and running on the *four-stroke cycle*, is shown on Pl. **41**. It consists essentially of a piston connected to a

PLATE 41.

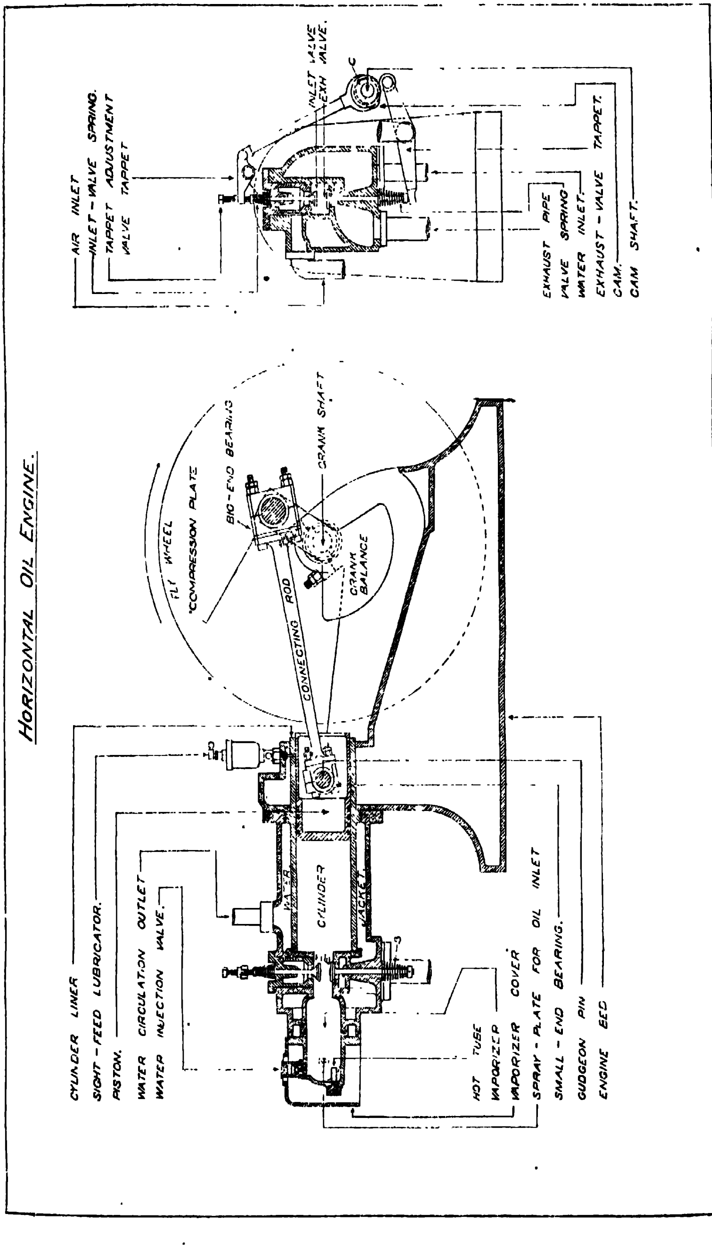
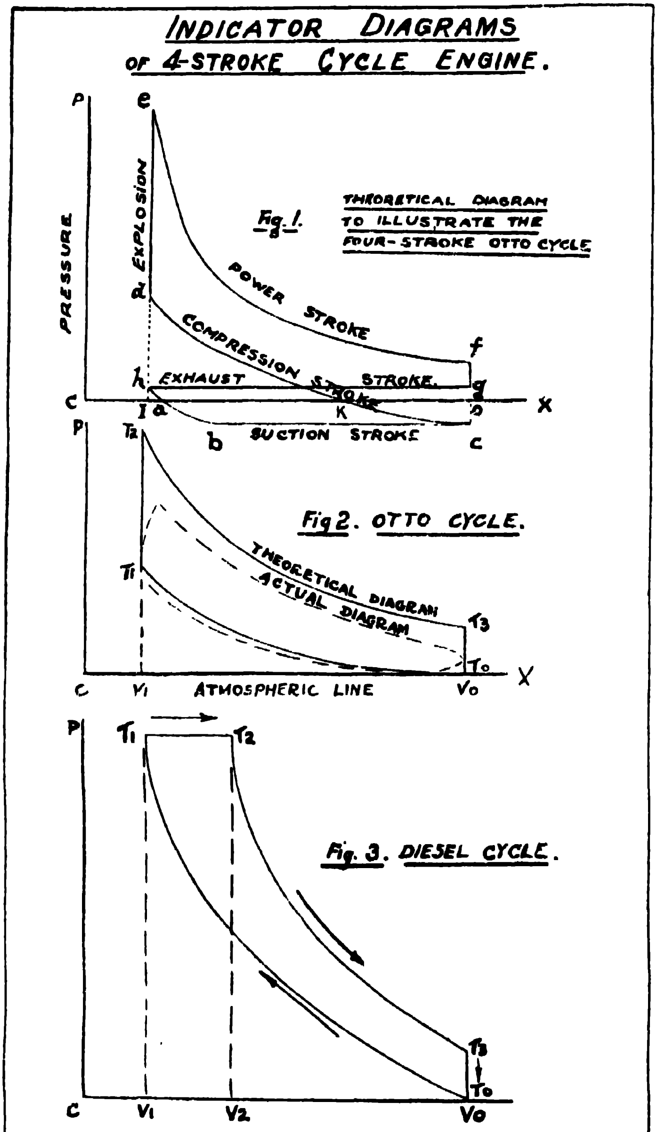

HORIZONTAL OIL ENGINE.
AIR INLET
INLET-VALVE SPRING.
TAPPET ADJUSTMENT
VALVE TAPPET
INLET VALVE
EXH VALVE.
EXHAUST PIPE
VALVE SPRING
WATER INLET.
EXHAUST-VALVE TAPPET.
CAM.
CAM SHAFT.
FLY WHEEL
COMPRESSION PLATE
BIG-END BEARING
CRANK SHAFT
CRANK BALANCE
CONNECTING ROD
CYLINDER
WATER JACKET
CYLINDER LINER
SIGHT-FEED LUBRICATOR.
PISTON.
WATER CIRCULATION OUTLET
WATER INJECTION VALVE.
HOT TUBE
VAPORIZER
VAPORIZER COVER
SPRAY-PLATE FOR OIL INLET
SMALL-END BEARING.
GUDGEON PIN
ENGINE BED

PLATE 42.


INDICATOR DIAGRAMS
OF 4-STROKE CYCLE ENGINE.
Fig. 1.
THEORETICAL DIAGRAM TO ILLUSTRATE THE FOUR-STROKE OTTO CYCLE
PRESSURE
EXPLOSION
POWER STROKE
COMPRESSION STROKE
EXHAUST STROKE
SUCTION STROKE
Fig 2. OTTO CYCLE.
THEORETICAL DIAGRAM
ACTUAL DIAGRAM
ATMOSPHERIC LINE
Fig. 3. DIESEL CYCLE.

crankshaft, by a connecting rod. An inlet valve, I, and an exhaust valve, E, are kept normally closed by strong helical springs, S, and can be opened at the right time by cams, C, revolving on the half-time shaft, which makes one revolution to two of the crankshaft, from which it is driven by gearing.

2. The four strokes of the cycle are briefly as follows (Pl. **42**, Fig. 1) :—

i. *Induction or suction stroke.*—The inlet valve is open and the exhaust valve closed. The piston is drawn outwards by the flywheel and sucks a mixture of oil (previously vaporized) and air into the cylinder through the inlet valve. Both valves are closed at the end of the stroke.

ii. *Compression stroke.*—Both valves are closed. The return stroke of the piston compresses the explosive mixture into the compression chamber, the necessary energy still being supplied by the flywheel. Just before the end of the stroke (inner dead centre) the charge is ignited, and burns practically instantaneously. The heat of combustion raises the temperature of the gaseous mixture in the cylinder, and hence its pressure.

iii. *Power stroke.*—The momentum of the flywheel pulls the piston over inner dead centre, and the pressure of the burning mixture behind it forces the piston back with gradually decreasing force throughout the stroke as the products of combustion expand and the pressure falls. Both valves remain closed during this stroke.

iv. *Exhaust stroke.*—The exhaust valve is open and the inlet valve closed. The in-going piston sweeps the expanded products of combustion out at the exhaust valve opening.

3. The four strokes make up one cycle, which is completed in two revolutions of the flywheel. The power stroke alone gives an impulse to the piston ; the other three strokes are necessary to the action of the engine, but absorb some of its power. The revolving flywheel serves as a reservoir of energy for driving the piston during its three non-productive strokes, and is made of sufficient weight and diameter to prevent any great fluctuation of engine speed during any one cycle.

4. **Graphical representation of the cycle.**—Referring to Pl. **42**, Fig. 1, let various positions of the stroke be plotted along CX, and pressure inside the cylinder along CP. Let I and O represent positions of *inner* and *outer* dead centre, so that IO represents the length of the stroke. Also let the line CX represent atmospheric pressure. Then the

graph for the suction stroke will be represented by *habc*, below the atmospheric line. The reason for this is that the piston must move outwards and form a partial vacuum in the cylinder before the charge will begin to be drawn in, and, similarly, the vacuum must always precede the charge throughout the stroke. At *c* the inlet valve closes, and the compression stroke, of which *cd* is the graph, begins. The compression may be considered to be *adiabatic*, which means that there is no transference of heat between the compressed mixture and the cylinder walls, &c. This has been verified by experiment as being approximately correct. The higher the speed, the less time will there be for transmission of heat, and the more truly adiabatic will the compression become. The temperature of the mixture is higher at *d* than at *c*, but this is due to the work done on it during compression by the piston (*i.e.* conversion of work into heat), in the same way as air compressed in a cycle pump heats up. At *d* the compressed charge is assumed to burn instantaneously, and the heat of combustion causes the pressure inside the cylinder to rise to a point, *e*.

The curve *ef* represents pressures at any point during the power stroke, the expansion of the products of combustion being also *adiabatic*. The gases, however, cool down from *e* to *f*, as they do work in giving the push to the piston. When the exhaust valve opens, the pressure falls almost instantaneously from *f* to *g*, and the line of pressures, *gh*, during the exhaust stroke is slightly above the atmospheric line, as the piston has to push the exhaust gases remaining in the cylinder out through the relatively small valve opening.

5. In an engine in practice the exhaust and inlet pressure lines are to all intents and purposes coincident with the atmospheric line as shown in Pl. **42**, Fig. 2. In Fig. 1, their positions above and below the atmospheric line respectively have been exaggerated for clearness.

Further, it must be noted that in practice the valves do not open and close exactly at the beginning and end of the stroke, and they do not open and close instantaneously. Moreover, combustion does not occur instantaneously at the end of the compression stroke. These imperfections have the effect of rounding off the diagram as shown dotted in Fig. 2.

6. **Efficiency of constant volume cycle.**—The Otto cycle is known as the *constant volume* cycle because, theoretically, the heat of combustion is added instantaneously to the gases inside the cylinder whilst the piston is at inner dead centre, and their volume remains the same. Similarly, the useful heat having been extracted from the products of combustion by the time the exhaust valve or port opens at outer

dead centre, the wasted heat may be regarded as leaving the engine at this point.

On Pl. **42,** Fig. 2, let T_1 be the temperature of the charge after compression, T_2 after combustion at inner dead centre, T_3 just before the exhaust valve opens, and T_0 of the entering charge.

Let V_1 and V_0 be the volumes between piston and cylinder end at inner and outer dead centres respectively.

Then thermal efficiency

$$= \frac{\text{heat turned into work}}{\text{heat supplied}}$$

$$= \frac{\text{heat supplied} - \text{heat rejected}}{\text{heat supplied}}$$

$$= 1 - \frac{\text{heat rejected}}{\text{heat supplied}} = 1 - \frac{K_v (T_3 - T_0)}{K_v (T_2 - T_1)}.$$

From equations (3) and (7) above we have

$$\frac{PV^{1\cdot4}}{\frac{PV}{T}} = \text{a constant}$$

$$\therefore TV^{0\cdot4} = \text{a constant}.$$

By assumption, the volume is V_0 both at T_3 and T_0 and V_1 both at T_2 and T_1.

$$\therefore \frac{T_1}{T_0} = \frac{T_2}{T_3} = \left(\frac{V_0}{V_1}\right)^{0\cdot4} = \frac{T_2 - T_1}{T_3 - T_0}.$$

Therefore the thermal efficiency $= 1 - \left(\frac{V_1}{V_0}\right)^{0\cdot4}$.

Now $\frac{V_0}{V_1} = \frac{\text{volume at outer dead centre}}{\text{volume at inner dead centre}} = \frac{\text{total cylinder volume}}{\text{clearance volume}}$

is known as the *compression ratio* and denoted by r.

$\therefore$ *thermal efficiency* $= 1 - \left(\frac{1}{r}\right)^{0\cdot4}$.

(If $r = 5$, the thermal efficiency $= 47\cdot5$ per cent.)

This is the maximum theoretical thermal efficiency it is possible to realize in an engine working on the constant volume cycle. It is known as *the Air Standard Efficiency.*

It will be noted that the higher the compression ratio, the greater the efficiency.

In practice the compression ratio is limited by detonation and by mechanical considerations.

7. The Diesel (constant pressure) cycle.—In the *Diesel* engine the detonation difficulty is overcome in the

following way. In the suction stroke, air only is drawn into the cylinder and the compression pressure is therefore limited merely by mechanical considerations. Pressures up to 500–600 lb./sq. inch are used in practice.

At the end of the compression stroke the fuel is admitted and ignited by the heat of the compression alone. The fuel is sprayed in at such a rate that, theoretically, there is no rise of pressure and by the time the last particle of fuel has entered and been burnt the piston has moved some distance forward on its working stroke. Theoretically, therefore, the combustion takes place at *constant pressure.*

The ideal pressure diagram is shown in Pl. **42**, Fig. 3, from which it will be noted that the working stroke bears a close resemblance to the working stroke in a steam engine with a very early cut off.

8. Efficiency of constant pressure cycle.—

Heat generated by combustion $= K_p(T_2 - T_1)$.
Heat lost in the exhaust $= K_v(T_3 - T_0)$.

$\therefore$ Heat converted into mechanical work, assuming adiabatic expansion and compression

$$= K_p(T_2 - T_1) - K_v(T_3 - T_0).$$

$$\textit{The thermal efficiency} = \frac{\text{heat turned into work}}{\text{heat supplied}}$$

$$= 1 - \frac{K_v(T_3 - T_0)}{K_p(T_2 - T_1)} = 1 - \frac{T_3 - T_0}{1{\cdot}4(T_2 - T_1)}$$

Thus the specific heats do not cancel out as they do in the constant volume formula.

This can be expressed thus :—

$$1 - \frac{T_3 - T_0}{1{\cdot}4(T_2 - T_1)} = 1 - \frac{\left(\frac{1}{r}\right)^{0{\cdot}4}(K^{1{\cdot}4} - 1)}{1{\cdot}4(K - 1)}$$

in which r = compression ratio as before and

$$K = \frac{V_2}{V_1} = \textit{constant pressure expansion ratio.}$$

It will be found by trial that, *for the same compression ratio*, the Otto cycle is more efficient than the Diesel, but as explained before the Otto engine cannot use such high compression ratios as the Diesel.

It is also interesting to note that the smaller K becomes the higher the efficiency. Therefore, theoretically at least, the Diesel engine becomes more efficient thermally as its load is reduced.

9. **Four-stroke and two-stroke cycles.**—In most engines the cycle of operations is completed in four strokes of the piston, there being one power stroke only in two revolutions, but in a large number of engines the cycle is completed in two strokes. The relative practical advantages and disadvantages of the two types will be dealt with later, but so far as thermal efficiency is concerned it makes no difference whether the cycle of operation is completed in two or four strokes.

65. *Practical efficiencies*

1. In practice, the best engines attain 50 to 60 per cent. only of the theoretical thermal efficiencies deduced above, this percentage being known as the *efficiency ratio.*

The main reasons for this difference are :—

i. Loss of heat to the cylinder walls. This is carried away by the cooling water.
ii. Additional loss to exhaust, owing to the valve or port opening before the end of the power stroke.
iii. The combustion is not instantaneous.
iv. The maximum explosion pressure falls short of that expected by theory (*see* Pl. **42**, Fig. 2). This is thought to be due to the rise of specific heat of products of combustion at high temperatures.
v. The working substance is not pure air.

As an example take the figures for a gas engine given in Table U, page 273.

The air standard efficiency $= 1 - \left(\frac{1}{r}\right)^{0\cdot4} = 0\cdot475.$

The B.Th.U. consumed per B.H.P. hour = 10,450.

Brake thermal efficiency $= \frac{2{,}545}{10{,}450} = 0\cdot244.$

Mechanical efficiency $= 0\cdot8.$

$\therefore$ *Indicated thermal efficiency* $= \frac{0\cdot244}{0\cdot8} = 0\cdot305$

and the *efficiency ratio* $= \frac{0\cdot305}{0\cdot475} = 0\cdot64.$

For the average practical values of these quantities for other I.C. engines, *see* Table U.

Diagrams such as those shown on Pl. **42**, Fig. 2, can be obtained by means of an *indicator*, which is dealt with in Chap. XXX.

For Bibliography, see page 687.

CHAPTER XIII

PRACTICAL STROKES AND VALVE TIMING

66. *Four-stroke constant volume cycle engines*

1. It has been stated in Sec. **64** that in a practical engine the valves do not open and close instantaneously nor exactly at dead centre. The principles affecting valve-timing of four-stroke I.C. engines working on the constant volume cycle, will now be considered in this section and Sec. **68.**

2. **Suction stroke.**—Assuming that the inlet valve is open (or partly open) at inner dead centre and that the piston moves outwards, it will begin to form a partial vacuum in the cylinder, so that the charge, which is at atmospheric pressure, will begin to flow in. A partial vacuum must be formed before the charge will flow in, and, therefore, the line of pressure during this stroke is always below atmospheric. If the inlet valve closed exactly at *outer dead centre,* compression would start when the cylinder was filled with a charge below atmospheric pressure, and it would not be until point K on Pl. **42,** Fig. 1, was reached on the compression stroke that atmospheric pressure would be obtained.

In order to get the *greatest weight* of charge into the cylinder (resulting in maximum power), the inlet valve does not close until after the compression stroke has begun, so that the column of air in the inlet pipe, which is already in motion, may continue to flow into the cylinder until the pressure therein is atmospheric, or slightly above it. Of course, at this point the piston has already returned through a short distance (exaggerated in Pl. **42,** Fig. 1), but the net effect is to get more charge into the cylinder and, incidentally, to raise the pressure at the end of the compression stroke. The actual position of closing must vary in differently designed engines, but it is always after *outer dead centre.* [O.D.C.]

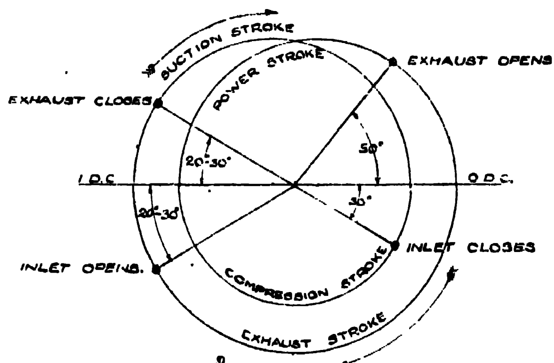
Pl. **43,** Fig. 1, gives a valve-timing diagram for an engine such as is shown on Pl. **41.**

3. **Compression stroke and ignition.**—In any engine, the heavier the weight of the charge the greater will be the final compression pressure. Ignition is commenced before *inner dead centre.* [I.D.C.] This is necessary because the charge does not burn instantaneously, but takes a definite time to do so. To obtain maximum power, the highest possible pressure is required very early in the power stroke.

PLATE 43.

TYPICAL VALVE TIMING ON 4-STROKE CYCLE ENGINE.

Fig. 1. TYPICAL VALVE-TIMING DIAGRAM FOR OIL ENGINE.



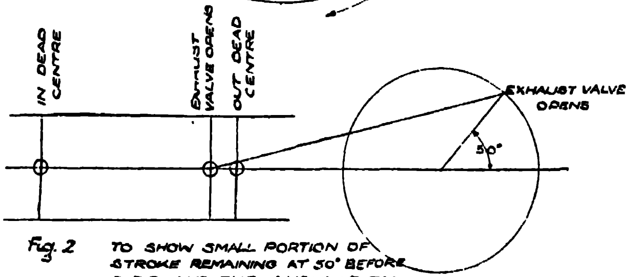


Fig. 2 TO SHOW SMALL PORTION OF STROKE REMAINING AT 50° BEFORE O.D.C. AND THE ANGULARITY OF THE CONNECTING ROD

Fig. 3. TO SHOW THE 'SCAVENGING' EFFECT AT THE END OF THE EXHAUST STROKE

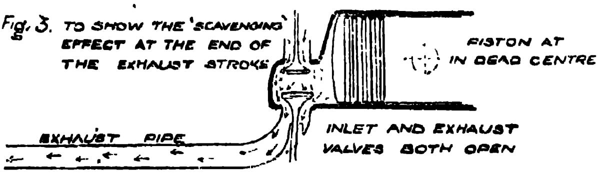
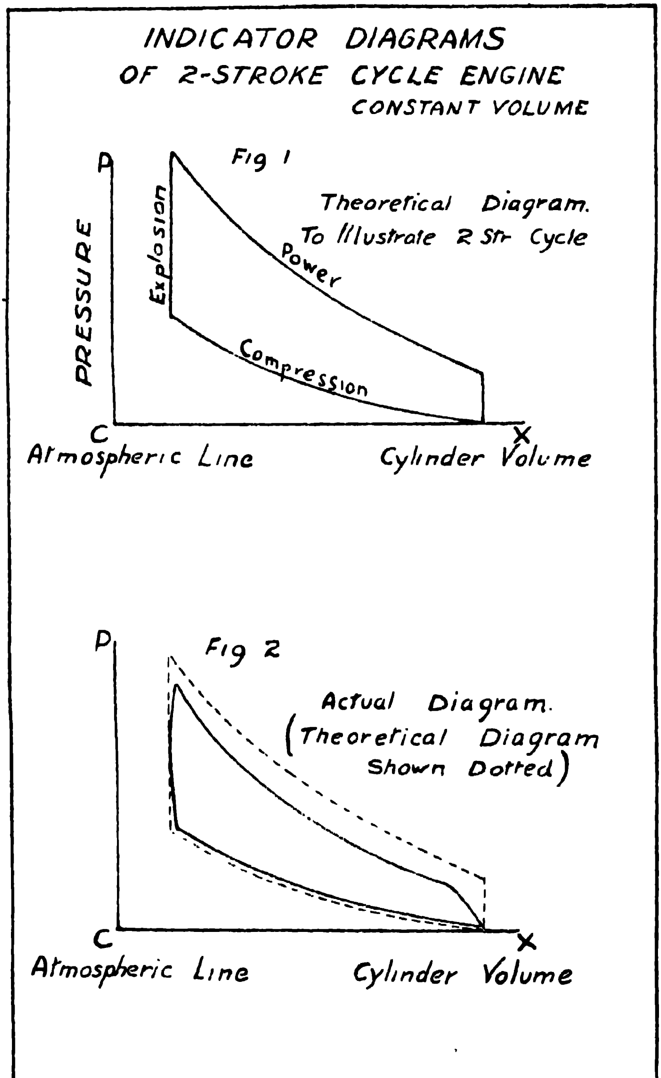


PLATE 44.


INDICATOR DIAGRAMS
OF 2-STROKE CYCLE ENGINE
CONSTANT VOLUME
Fig 1
P
PRESSURE
Explosion
Theoretical Diagram.
To Illustrate 2 Str Cycle
Power
Compression
C
X
Atmospheric Line
Cylinder Volume
Fig 2
P
Actual Diagram.
(Theoretical Diagram
Shown Dotted)
C
X
Atmospheric Line
Cylinder Volume

Maximum pressure can only be obtained when all the heat of combustion has been absorbed by the products of combustion. The actual point at which ignition should take place varies with the design, speed, load and temperature of the engine, with the strength of the explosive charge, and with its degree of compression, and has been dealt with in Sec. **62**.

4. **The power stroke.**—During this stroke the exhaust valve begins to open about 50° before *outer dead centre*. *See* Pl. **43**, Fig. 1. At first sight it would appear that by so doing much useful pressure would be wasted; but as the pressure at this point has dropped fairly low, and as for the short remainder of the stroke, Pl. **43**, Fig. 2, the connecting rod and crank are nearly in line, little power is thereby lost. By opening the valve at this point, the pressure of the burnt gases in the cylinder is reduced nearly to atmospheric by the end of the stroke. When the exhaust stroke begins, there only remains a cylinder full of combustion products, at slightly above atmospheric pressure, to push out of the cylinder, and therefore the back pressure on the piston during this idle stroke is reduced to a minimum.

5. **The exhaust stroke.**—In this stroke the inlet valve opens before *inner dead centre;* it is also seen from Pl. **43**, Fig. 1, that the exhaust valve does not close until after the suction stroke has commenced. This ensures that all the burnt gases are swept out, and that the cylinder is filled, during the suction stroke, with fresh mixture only. The push imparted to burnt gases by the piston on the exhaust stroke will give them such momentum that they will continue to move through the valve opening after the cylinder pressure is reduced to atmospheric pressure. If at this moment the inlet valve is opened, air at atmospheric pressure will flow in through it, and will tend to help the burnt gases to continue their movement through the exhaust opening, Pl. **43**, Fig. 3. This process is known as *scavenging*, and ensures that the explosive charge for the next stroke is not mixed with burnt gases from the last cycle. This overlap of inlet and exhaust valves is usual in low-speed engines, though it is, of course, more effective in the case of engines having valves on opposite sides of the cylinder than with those having side by side valves.

67. *Two-stroke cycle engines*

1. The graphical representation (indicator diagram) of the two-stroke constant volume cycle is shown on Pl. **44**. It is practically the same as for the four-stroke constant volume cycle (Pl. **42**, Fig. 1), except that the suction and exhaust

strokes do not appear. The compression and expansion curves are approximately adiabatic as before.

The engine described in the following paragraphs, however, compresses air only and works on a cycle which lies between the constant volume and constant pressure cycles. It is, however, typical of practical two-stroke engines which seldom work on the true constant volume cycle.

2. Referring to Pl. **75**, p. 387, and considering the cycle of operations taking place on both sides of the piston, *i.e.* in the cylinder and in the totally enclosed crankcase, air, which had been drawn into the crankcase through automatic disc valves, D, when the piston was moving upwards on the previous stroke, has been compressed in the crankcase by the subsequent downward movement of the piston. This air is now being transferred to the upper side of the piston by way of the transfer port, I, which is only open when the piston is at or near the lower end of its stroke.

Owing to the shape of the top of the piston, this air does not escape direct through the open exhaust port, G, but passes round the upper end of the cylinder as indicated by the arrows. In doing so, it *scavenges* the cylinder of the burnt gases from the previous explosion, forcing them out to exhaust through the port, G.

The momentum of the flywheel now carries the piston upwards, closing ports I, and later G, thus trapping the air and compressing it in the cylinder.

When the piston is near the top of its stroke, fuel in the form of a fine spray is forced in by means of a fuel pump (not shown) and *atomiser* or *spraymaker*. The heat of compression, combined with the heat of a purposely uncooled portion of the cylinder head, cause a rapid burning or explosion of the air and fuel mixture to take place, with consequent rapid rise of pressure.

The piston is now forced downwards, imparting momentum to the flywheel and doing useful work, until port G is uncovered, when the burnt gases escape to atmosphere via the exhaust. Slightly later, the port I is uncovered, allowing a new charge of air (which had been sucked into and compressed in the crankcase as in 1) to enter and scavenge the remaining burnt gases.

Another cycle then commences.

3. It will be observed that there is one power stroke per revolution of the crankshaft, as compared with one power stroke per two revolutions of the crankshaft in the case of a four-stroke engine.

4. In Pl. **74**, Fig. 5, is shown the port timing diagram of a typical two-stroke engine such as is shown in Pl. **75**. It will

be noticed that the opening and closing points of each port are symmetrical about the *outer dead centre* (O.D.C.). This will be obviously unavoidable, since the ports are stationary, and it can be understood by referring to Pl. **75**.

5. Considering firstly the transfer port. In order to ensure complete transfer of the charge (which in the case in Pl. **75** is air only) from crankcase to cylinder at the speed and with the amount of crankcase compression usually found in such an engine (some 6 lb. per sq. in. gauge), it is necessary that the upper edge of the transfer port be cut so that opening and closing takes place about 50° of crank angle from the O.D.C. This gives a total opening of 100° of crank angle, the port being fully open only at the outer dead centre. This, with ports extending sideways to some third of the circumference of the cylinder, allows unrestricted transfer to take place.

6. The exhaust port must open before the transfer port so that the cylinder pressure has time to fall below the crankcase pressure by the time the transfer port opens. Otherwise the exhaust products would pass down the transfer port into the crankcase.

In order to attain this end it is necessary to have the exhaust port open some 65° before O.D.C., which is earlier than in the case of the exhaust valve in a four-stroke engine.

This means that, for the same maximum pressure the two-stroke engine is not quite so efficient as the four-stroke, but the difference on this account is small.

7. Considering the closing points of both ports, the exhaust port must of necessity close later than the transfer port. This at once introduces the risk of loss of the new charge through the exhaust port, in spite of the specially designed deflector on the piston top. This loss of charge is primarily responsible for the relatively poor thermal efficiency of two-stroke engines as compared with four-stroke *in cases where fuel and air are compressed in the crankcase.* It is most noticeable when such two-strokes are run at speeds lower than that for which they were designed.

68. *Valve timing*

1. *The exact setting of valves to open and close at the correct time is important, as it affects not only the power that can be developed by the engine, but also the fuel consumption.*

The factors normally affecting the valve timing are :—

i. The meshing of gears driving the half-time shaft. The correct position is usually indicated by a pip mark on the teeth.

ii. The adjustment of tappets or their levers, and the wear of valves owing to grinding in.

Even though (i) is correct, an inexperienced operator may have his tappets so adjusted that the valves remain open for too long or too short a period.

Valve settings, therefore, require constant checking by officers and mechanists.

Although a knowledge of the principles enunciated in this chapter will enable a fair setting to be made, *manufacturer's instructions on the point should be worked to when they are available.*

2. **Changing direction of rotation.**—The majority of oil engines are designed to run as shown on Pl. **41.** It is, however, possible to reverse the direction of rotation in some four-strokes by so altering the cams that the valves are made to open and close at the correct instant in the reversed cycle.

In the case of two-strokes, the port timing is the same for either direction of rotation.

For further instructions as to changing direction of rotation (as regards ignition), *see* Sec. **87,** para. 12, *and* Sec. **96,** para. 9.

CHAPTER XIV

TYPES AND RATING OF I.C. ENGINES

69. *Types of I.C. engines*

1. The various types of I.C. engines may be conveniently classified as follows :—

i. *Gas engines.*
ii. *Petrol engines.*
iii. *Oil engines.*
iv. *Heavy oil engines.*—Semi-Diesel.
v. *Heavy oil engines.*—Diesel. $\left\{\begin{array}{l}\text{Solid injection.}\\\text{Air injection.}\end{array}\right.$

In types (i), (ii) and (iii) a gas or vapour mixture is compressed and the compression pressures are therefore necessarily low. Ignition is effected by an electric spark or hot bulb, the increase of temperature due to compression being relatively negligible. In (iv) and (v), air only is compressed, and the fuel is introduced at the end of the compression stroke.

i. *Gas engines* were the first type of I.C. engine introduced and are perhaps the simplest in operation. They will seldom be met with in the service, but it should be remembered that practically any type of petrol or oil engine can be converted to run on coal gas or producer gas.

ii. *Petrol engines.*—This type is considered next as the fuel more nearly approaches a gas than any other liquid fuel. Petrol engines are mainly of the four-stroke, high-speed type, running at from 1,000 to 2,000 r.p.m. and having therefore a relatively high power weight ratio. Apart from road vehicles, they are largely used for stationary work in the service in small sizes up to (say) 40 B.H.P., on account of their lightness, portability and quickness of starting. Owing to their extensive use in road vehicles they are perhaps better understood generally than any other type of engine, but they are expensive to run and have a short life.

The ordinary petrol engine can also be run on paraffin (with a reduced output) if a vaporizer is fitted.

iii. *Oil engines.*—Chronologically, the low-compression, low-speed engines burning paraffin, popularly known as *oil engines*, come next to the gas engine. They are extremely simple to operate, cheap in first cost and have a long life. Although now being largely superseded by more efficient engines burning cheaper fuels, low-compression oil engines still have a wide application in small sizes. They suffer from the disadvantage that some 20 minutes is necessary to heat up a vaporizer before the engine can be started.

iv. *Semi-Diesel engines.*—The Diesel Engine Users' Association's definition of a *semi-Diesel* is as follows: "A semi-Diesel engine is a prime mover actuated by the gases resulting from the combustion of a hydro-carbon oil. A charge of oil is injected in the form of a spray into a combustion space open to the cylinder of the engine at or about the time of maximum compression in the cylinder. The heat derived from an uncooled portion of the combustion chamber, together with the heat generated by the compression of the air to a moderate temperature, ignites the charge. The combustion of the charge takes place at, or approximately at, constant volume."

This type of engine was introduced in the days when there was no alternative between the air blast Diesel engine burning cheap fuel oil and the low-compression oil engine burning the much more expensive paraffin, in an attempt to produce an engine burning cheap fuel approaching the Diesel in efficiency but which, by using lower compression pressures, could be produced in a comparatively light and cheap form. The majority of semi-Diesels work on the two-stroke cycle. This type of engine will not start from cold without some special device, and although having a high thermal efficiency, the necessity for a hot bulb is a disadvantage and the solid injection Diesel engine is now superseding it except in small sizes (say) up to 25 B.H.P.

v. *Diesel engines.*—The D.E.U.A.'s definition of a *Diesel engine* is as follows: "A *Diesel* engine is a prime mover actuated by the gases resulting from the combustion of a liquid or pulverized fuel injected in a fine state of sub-division into the engine cylinder at or about the conclusion of the compression stroke. The heat generated by the compression to a high temperature of air within the cylinder is the sole means of igniting the charge. The combustion of

the charge proceeds at, or approximately at, constant pressure. There are actually two sub-types of Diesel :—

"(*a*) The true Diesel, in which the fuel is blown into the cylinder by an air blast. This type works on the constant pressure cycle. *See* Sec. **97**.

"(*b*) The airless injection type in which the blast air for fuel injection is dispensed with, and solid injection, *i.e.* injection by mechanical pump is substituted. This type works usually on a cross between constant-volume and constant-pressure cycle, but comes within the Diesel Engine Users' Association's definition of *Diesel*."

In large sizes there is no doubt that the air blast injection Diesel is the most economical type of I.C. engine. Both four-stroke and two-stroke designs are common.

The solid injection type popularly known as a *cold starter* is not quite so efficient nor so quiet in operation as the air injection type, but the absence of a compressor makes the former the simpler of the two. The solid injection type may now be considered as the most suitable for service purposes in sizes of (say) 25 B.H.P. upwards.

vi. *High-speed heavy-oil engines.*—The majority of Diesel engines run at low speeds of the order 150–400 r.p.m. and are relatively large and expensive, but most manufacturers have recently developed designs running at much higher speeds which should prove both lighter and cheaper for stationary work generally. Also the high price of petrol and the improvements in the properties of engineering materials have caused attention to be focussed upon the production of a comparatively small Diesel type of engine, burning cheap fuel oil which will run at high speeds of the order 1,000–2,000 r.p.m. and give a power weight ratio approaching that of the petrol engine. A number of successful designs of this type of engine, known popularly as the *compression-ignition* engine (all Diesel engines are, of course, compression-ignition engines), are now in use in road vehicles, and it is possible that this type may replace the petrol engine for service purposes in the not very remote future.

2. Table U and Pl. **45** summarize the salient features of the various types of engines referred to above. There is nothing precise about the figures given in the table (higher values for the M.E.P. will be met in some cases). They are typical of small engines up to about 40 B.H.P., the gas, oil and semi-Diesel being low speed (about 200–300 r.p.m.), and the petrol, high speed (1,000–2,000 r.p.m.). In the Diesel engines the figures apply roughly to sizes from 100–500 B.H.P.

These engines will be dealt with in more detail in the following chapters.

3. **Four-stroke and two-stroke cycle engines.**—There is little to choose between modern designs of four-stroke and two-stroke engines. The weight and first cost of engines of similar output are approximately equal. In the smaller sizes, the two-stroke has a slightly higher fuel and lubricating oil consumption. The absence of valves in the cylinder head of the two-stroke makes for simplicity, and its torque is more even, but against these advantages may be alleged the uneven stresses and wear in the cylinder due to a hot exhaust port on one side and a cool inlet on the other, and the necessity for an air-tight crankcase.

The use of fuel oil and compression ignition introduce a new factor in favour of the two-stroke engine. No fuel is admitted until towards the end of the compression stroke and scavenging is therefore carried out by means of pure air. The loss of a certain amount of this air through the exhaust port is of small importance if it carries no fuel with it and, therefore, more thorough scavenging can be obtained than with the petrol engine. Further, if air only is compressed in the crankcase, no direct dilution of the lubricating oil takes place.

Generally, however, for small and medium size engines, the four-stroke is more popular than the two-stroke cycle engine.

70. *The rating of I.C. engines*

1. The B.H.P. which an engine is capable of developing is proportional to the following :—

(*a*) The indicated work per stroke.
(*b*) The number of working strokes in unit time.
(*c*) The mechanical efficiency.

The indicated work is proportional to—

i. The indicated mean effective pressure (I.M.E.P.). *See* Sec. **140**.
ii. The volume displaced per stroke by the piston.

The higher the combustion pressure the higher the I.M.E.P. and the working temperatures, and therefore the maximum horsepower which an engine can safely develop is

TABLE U.—*Typical data of four-stroke I.C. engines*

Type of engine	Gas	Petrol	Oil	Semi-Diesel	Solid injection	Diesel air injection
Fuel used	Town gas	Petrol	Paraffin	Gas oil	Heavy fuel oil	Heavy fuel oil
Gross heat value of fuel (B.Th.U. per lb.)	550 (per cu. ft.)	18,500	18,500	19,000	19,000	19,000
Medium compressed ..	Gas-air mixture.	Vapour-air mixture.	Vapour-air mixture.	Pure air	Pure air	Pure air
Compression pressure, maximum (lb./sq. in.).	120	100	70	150*	400	500
Approximate compression ratio.	5·0	4·5	3·5	6·5	12	15
Method of vaporization ..	—	Carburettor	Separate vaporizer.	Sprayer and hot surface and heat of compression.	Sprayer and heat of compression.	Sprayer and heat of compression.
Method of ignition	Spark	Spark	Spark or hot surface.	Hot surface and heat of compression.	Heat of compression.	Heat of compression.
Type of combustion	Constant volume.	Constant volume.	Constant volume.	Constant volume.	Cycle between c.v. and c. pressure.	Constant pressure.
Maximum combustion pressure (lb./sq. in.) full load.	300	250	150	300	600	525
Indicated M.E.P. (lb./sq. in.) at full load.	80	75	55	85	95	100
Mechanical efficiency (per cent.) at full load.	80	85	80	85	85	75
Brake M.E.P. (lb./sq. in.) at full load.	64	64	44	72	81	75
Efficiency ratio $= \frac{\text{indicated thermal efficiency}}{\text{air standard efficiency}}$	0·64	0·58	0·66	0·63	0·64	0·68
Fuel used per B.H.P. hour (lb.) at full load.	19 (cu. ft.)	0·60	0·65	0·47	0·41	0·40
B.Th.U. per B.H.P. hour, at full load.	10,450	11,100	12,000	8,930	7,790	7,600
Brake thermal efficiency (per cent.) at full load.	24·4	23·0	21·2	28·5	32·7	33·5

* Some designs use compression pressures up to 250–300.

PLATE 45.

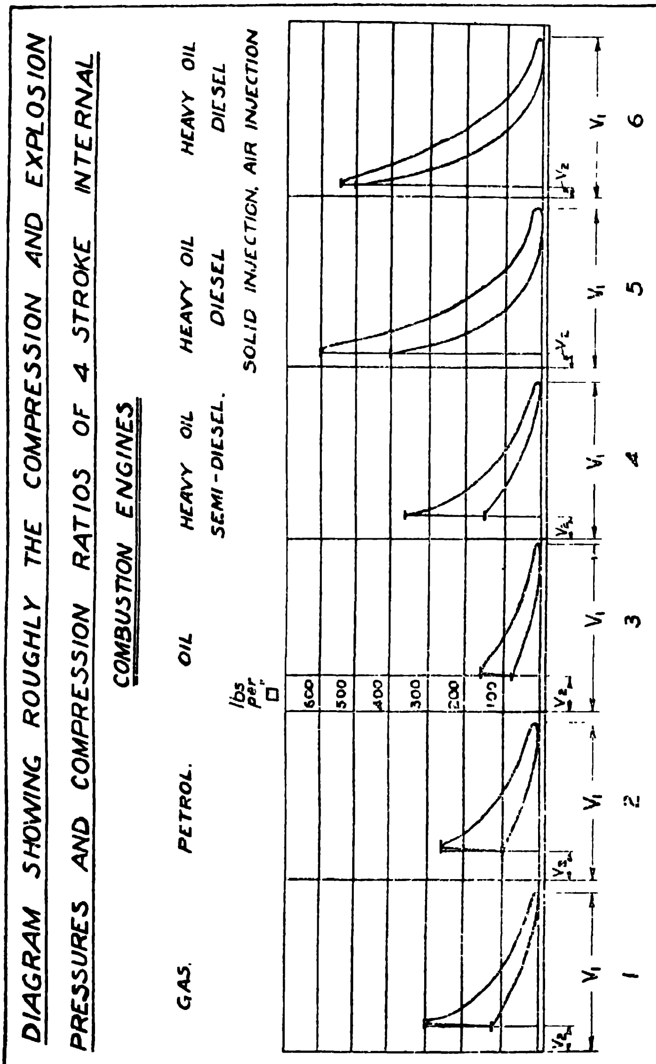


DIAGRAM SHOWING ROUGHLY THE COMPRESSION AND EXPLOSION
PRESSURES AND COMPRESSION RATIOS OF 4 STROKE INTERNAL
COMBUSTION ENGINES
GAS.
PETROL.
OIL
HEAVY OIL
SEMI-DIESEL.
HEAVY OIL
DIESEL
SOLID INJECTION
HEAVY OIL
DIESEL
AIR INJECTION
lbs per □"
600
500
400
300
200
100
V_2
V_1
1
2
3
4
5
6

limited by the thermal and mechanical characteristics of the materials used in the construction. The design is, of course, a matter for the manufacturer, who is forced for competitive reasons to work with as low a margin of safety as possible and, therefore, a clear definition to check the manufacturer's rating is obviously desirable.

2. In the past it has been considered wise not to run I.C. engines for long periods at loads as great as the manufacturer's rating, and where no recognized standard of performance exists the practice is sound. (*See* Table **Z**, page 546.)

There are, however, for heavy oil engines driving electric generators, three British Standard Specifications (*see* Bibliography) from which the following have been extracted :—

i. *Rated output.*—The rated output of the engine shall be the load in brake-horse-power which it is capable of carrying continuously for a period of *twelve hours* at its rated speed when working under the following conditions :—

Barometric pressure—30 in. of mercury.

Atmospheric temperature—62° F.

For continuous day and night running, the maximum continuous load on the engine shall be 10 per cent. less than the rated output.

ii. *Overload.*—The engine shall be capable for periods of one hour of developing a load of 10 per cent. above its rated output without undue heating or mechanical trouble.

iii. The specifications also lay down that for direct coupled sets the engine rating should be 1·5 times the generator rating in k.W., assuming a generator efficiency of 89·5 per cent.

For belt- or rope-driven machines the engine rating is increased by 5 per cent.

If the generator is to be called upon to carry any continuous overload in excess of 10 per cent. for any period this overload should be allowed for.

For example, a 100-k.W. generator capable of 15 per cent. sustained overload would necessitate an engine for direct-coupling and continuous day and night running *rated* at

$$115 \times 1{\cdot}5 \times 1{\cdot}1 = 190 \text{ B.H.P.}$$

iv. *Allowances for non-standard atmospheric conditions.*

(*a*) *Altitude.*—Four per cent. decrease in rated output *per* 1 inch decrease of mercury.

(*b*) *Temperature.*—Two per cent. decrease in rated output *per* 10° F. increase in temperature.

For example, suppose an engine is required to develop 100 B.H.P. at an altitude of 5,000 feet. Assuming approximately 1 in. decrease in mercury for 1,000 feet altitude, the *standard rating* must be $\frac{100}{0{\cdot}8} = 125$ B.H.P. at 62° F.

3. There are no B.S. Specifications for other types of I.C. engines, but those for heavy-oil engines may be used as guides for all types.

4. High-speed petrol engines when direct-coupled should have a B.H.P. rating equal to *twice* the rating of the electric generator in k.W.

The treasury rating for high-speed petrol engines used in road vehicles is :—

$$\text{B.H.P.} = 0{\cdot}4\ D^2N,$$

where D = diameter of piston in inches,
and N = number of cylinders.

This is based upon a piston speed of about 1,000 feet per minute and a brake mean effective pressure of about 67 lb./sq. in., and may be used as a guide when assessing the rating of this type of engine for stationary running on petrol. On paraffin the B.H.P. will be 20 per cent. less.

5. **Supercharging.**—It was pointed out in Sec. **63** that an I.C. engine is really an air engine, and it follows that the greater the weight of air present in the cylinder at the beginning of the compression stroke the greater the quantity of fuel which can be burnt and the greater the power the engine can develop.

When air enters the cylinder its temperature is raised by mixing with the hot exhaust gases remaining in the clearance space from the previous cycle, and also by coming into contact with the hot walls of the cylinder, while its pressure is reduced somewhat as the rapidly moving piston produces a slight vacuum in the cylinder. The drop in pressure depends on the speed of the piston and the adequacy of the inlet-valve and port areas, and it is readily ascertained by a light spring indicator diagram.

The efficiency with which the suction stroke performs its function of re-charging the cylinder with fresh air is called the *volumetric efficiency* which

$$= \frac{\text{Volume of fresh air drawn in (at N.T.P.)}}{\text{Volume swept by the piston}}.$$

In four-stroke engines the value is from 80–85 per cent. for low piston speeds, but may be as low as 70 per cent. with very high piston speeds. In small high-speed two-stroke engines the value may be only 50 per cent. (The effective

volumetric efficiency will naturally be smaller still at high altitudes.)

If, however, air is introduced into the cylinder under pressure, the rated output of an engine of given size can be very much increased, and the engine is then said to be *supercharged.*

In the *Buchi* system the exhaust gases are used to drive a turbo-compressor to give a cylinder charging pressure well above atmospheric which results in—

(1) A larger weight of air due to higher pressure and lower temperature.

(2) A smaller exhaust gas residue owing to more efficient scavenging.

(3) A very efficient internal cooling effect.

A charging pressure of 5 lb./sq. inch above atmospheric enables the rating of an engine of given size to be increased by 50 per cent., the only appreciable modification in design necessary in Diesel engines being a small increase in crankshaft diameter to deal with the greater output. This is possible because the maximum cylinder pressure and temperature are no greater in the supercharged engine than in the ordinary one. The maximum combustion pressures are the same in both cases, but in the supercharged engine the combustion continues for a longer period and therefore the indicated M.E.P. is greater.

It will be clear from the above that for a given power the supercharged engine is lighter, smaller and cheaper.

Supercharging is largely used in marine and aircraft engines and is now being applied to both air injection and solid injection engines.

CHAPTER XV

GOVERNING, LUBRICATION, AIR FILTERING, COOLING AND SILENCING OF I.C. ENGINES

71. *Governing of I.C. engines*

1. **Speed regulation.**—Engines are normally designed to run at maximum efficiency when doing a certain definite amount of work *per cycle*, and therefore to maintain the best efficiency they should run at a speed proportional to the load.

This is, of course, seldom practicable in stationary work, where the speed should be as constant as possible at all loads. The full load *speed regulation* is defined as follows :—

$$\textit{Speed regulation} = \frac{\text{Rise in speed when full load is suddenly removed}}{\text{Rated full load speed}} \times 100 \text{ per cent.}$$

e.g. if the speed rises from 300 to 315 from full load to no load the speed regulation is 5 per cent.

To realize this approximate constancy of speed it is necessary to alter the fuel supply automatically as the load varies, and it is the function of the *governor* to effect this with as little variation in engine speed as possible.

The governor (Pl. **46**, Fig. 1).—Whatever method of fuel adjustment is adopted, the controlling mechanism is generally actuated by the motion of a sleeve (*b*) on a vertical or horizontal spindle. The sleeve derives its linear motion from two arms connected to revolving weights (*a*, *a*) driven by the engine. These weights are suspended in such a manner that their position relative to the axis of rotation varies with the centrifugal force acting on them, and therefore with the engine speed. The greater the linear motion of the sleeve corresponding to a given change in speed the greater is said to be the *sensitiveness* of the governor.

For reasons which cannot be explained here a governor is usually *loaded* with a weight or a spring, acting on the sleeve, to increase the sensitivity.

A governor which is infinitely sensitive, *i.e.* in which an infinitely small change in speed gives maximum motion of the sleeve is said to be *isochronous*. Although at first sight such a governor may seem to be ideal, it would really be of no practical use owing to its tendency to *hunt*. When the load is suddenly reduced the speed increases sufficiently to cut off the fuel supply completely. The speed then falls below normal,

thus giving a full supply of fuel and causing the engine to speed up again. This goes on for some time and the continual overshooting of the mark is termed *hunting.*

A practical governor, therefore, must be *stable* and maintain a definite position of equilibrium for any speed within its range, and there must be a definite difference of engine speed between no load and full load.

Where a close speed regulation is desired (as in electric power stations) the sensitivity of the governor is increased as far as practicable and a damping device such as an oil dashpot is fitted to reduce *hunting.*

For heavy oil engines in electric power station work it is usual to specify a speed regulation of 3 per cent. (momentary 6 per cent.) from full load to no load. The Standard Specifications, however, permit a change of $3\frac{1}{2}$ per cent. (7 per cent. momentary) for engines driving D.C. generators in parallel or A.C. generators singly and 5 per cent. (10 per cent. momentary) when driving A.C. generators in parallel.

For small high speed petrol engines, a speed regulation of 7–10 per cent. (14–20 per cent. momentary) is usual.

2. **Hand speed adjustment.**—Provision is always made (by altering the tension on the governor spring or otherwise) for adjusting the speed of the engine by hand, while running, independently of the governor control.

For heavy oil engines driving A.C. generators in parallel 7 per cent. above and below the rated speed must be provided for in this way. When driving D.C. generators $2\frac{1}{2}$ per cent. above and below is sufficient.

Larger adjustments can be provided for if desired, but it is not advisable to run continuously at speeds appreciably below the rated value, if close governing is desired, as the sensitivity of a governor is reduced at the lower speeds.

3. **Cyclic speed irregularity.**—The above discussion was limited to what may be termed the *mean or average speed* of the engine in revolutions per minute. But there is a considerable variation in driving torque throughout each revolution.

In the case of the single cylinder four-stroke cycle engine there is no driving torque at all during three strokes out of four and a *flywheel* is absolutely essential, as previously explained. In multicylinder engines the cyclic variations in driving torque are naturally much less, but a flywheel is always necessary to keep the *cyclic speed irregularity,* due to variations in driving torque and load torque, within reasonable limits.

Also included in the functions of the flywheel is the limitation of the momentary speed regulation referred to above. The governor has little control over this.

The *cyclic speed irregularity* is defined as :—

$$\frac{\text{Maximum speed} - \text{Minimum speed}}{\text{Mean speed}}$$

expressed as a fraction. It should not exceed the values given below for the loads specified :-

i. *Pumps*, $\frac{1}{20}$.
ii. *Machine tools*, $\frac{1}{35}$.
iii. *D.C. generators and A.C. generators (singly).*
 (*a*) Multicylinder engines, $\frac{1}{150}$.
 (*b*) Engines with one or two cylinders, $\frac{1}{75}$.

These low values are necessary to prevent flickering of the lamps and governor oscillation.

iv. *A.C. generators in parallel (additional requirement)*

$$\frac{k}{6p}$$

where k = number of engine impulses per revolution,
and p = number of poles in the generator.

This requirement ensures that the flywheel effect shall be such that the angular deviation, *i.e.* the amount the rotating part forges ahead or the amount it lags behind the position of uniform rotation, shall not at any time exceed $2\frac{1}{2}$ electrical degrees.

Engine manufacturers find no difficulty in complying with these figures and they can arrange for a cyclic speed irregularity as low as $\frac{1}{250}$ if required. This is the figure generally used for traction generators and specified by some engineers for A.C. generators running in parallel.

The figures given in (iii) and (iv) above, however, which are laid down in the British Standard Specifications, are low enough for all ordinary purposes.

4. **Weight of flywheel required.**—The kinetic energy (K.E.) stored in the rim of a flywheel

$$= 0{\cdot}00017.\text{W}.\text{K}^2.\text{N}^2 \text{ foot-lb.}$$

if W = weight of rim in pounds, K = radius of gyration = mean radius of rim in *feet* and N = revs. per *minute.*

(The total weight will be about 1·4 W, including the arms and boss, the K.E. of which is neglected here.)

The flywheel K.E. in foot-lb. required for a cyclic irregularity k, may be written :—

$$\text{K.E.} = \text{C}\left\{\frac{1{,}000 \times \text{I.H.P.}}{k.\text{N}}\right\}$$

in which the constant C has the following values for high compression engines :—

No. of cylinders	Four-stroke cycle		Two-stroke cycle	
	I.H.P. per cylinder	I.H.P. total	I.H.P. per cylinder	I.H.P. total
1	42	42	28	28
2	35·2	17·6	15·8	7·9
3	30·4	10·1	13·1	4·37
4	10·67	2·66	10·5	2·62
6	10·80	1·80	3·0	0·50

For low compression engines the flywheels may be some 20 to 30 per cent. lighter.

The flywheel effect of the rotor of an electric generator is considerable and may be allowed for when deciding upon the size of flywheel required.

5. **Methods of fuel adjustment.**—Three common methods of fuel adjustment are employed in I.C. engines.

(i) *Hit and miss governing*, in which the whole of the fuel is cut off for one or more strokes.

The method is simple, but the cyclic irregularity of the engine is great unless very heavy flywheels are used. It is rarely used now except on small and relatively unimportant engines.

(ii) *Quality governing* in which the quantity of fuel injected is altered to suit the load, *the air supply remaining constant.* Practically the only method now used in oil engines of all types.

Unsuitable for petrol or gas engines owing to the small range of explosive mixtures.

(iii) *Quantity governing* in which the *quantity* of the explosive mixture is altered to suit the load, the *ratio of air to fuel remaining constant.* Used in petrol engines and very largely in gas engines.

6. **Hit and miss governing.**—(i) In this method either—

(*a*) The fuel valve is kept closed for one or more strokes, or

(*b*) With automatic inlet valves, the exhaust is held open.

(ii) Pl. **46**. Fig. **1**, shows a centrifugal governor actuating a hit-and-miss gear. As the speed increases, the knife edge, *c*, moves downwards until it catches the stop, *d*, and holds the exhaust valve open. When the engine speed becomes normal

again, the governor balls drop, the knife edge, *c*, rises and becomes disengaged from *d*, the exhaust valve is closed, and the cycle is resumed.

(iii) Pl. **46**, Fig. 2, shows an *inertia* governor, on the *hit-and-miss* principle, as used in an old design of the Tangye oil engine. The pecker, *P*, is carried by a holder, *B*, hinged on the pin, *A*, and resting on a roller turning on a fixed pin, *C*.

A is borne in a bracket, *D*, to which a reciprocating motion is given by the cam, *E*. The lower edge of *B* is formed with an inclined surface, *K*, as shown. A spring, *H*, maintains a slight tension on one end of *B*, thus tending to preserve contact with the roller, *C*. At normal engine speeds the spring pressure is so adjusted that *B*, during its motion from right to left, does not part contact with *C*, and the pecker, *P*, then engages with the groove, *V*, and the exhaust valve is allowed to close.

At increased engine speeds, however, the upward momentum communicated to *B* by the reaction of the roller on the inclined surface, *K*, is sufficient to cause the pecker to fly above *V*. This results in the exhaust valve being held open owing to the engagement of the two hardened steel plates, *X* and *Y*.

7. **Quality governing.**—(i) This is effected either by—

(*a*) Varying the pump stroke, or

(*b*) Taking a full pump stroke every time and by-passing more or less oil, as the speed increases or decreases.

(ii) Pl. **47** shows the arrangement in the Hornsby oil engine. The governor sleeve actuates a rod, so that when the speed increases, the projecting piece, *b*, is forced down and opens a valve, *c*, against a spring. Oil is sprayed into the hot bulb through the holes, *d*. It enters from the oil pump at *e*, the force with which it is pumped being sufficient to open the fuel inlet valve, *f*, against the spring. At normal speeds, the valve *c* being closed, the whole of the oil pumped up per stroke is sprayed into the vaporizer through *d*. As the speed increases, the valve *c* is opened, and some of the oil pumped up makes its way past this valve through the return pipe, *g*, and back to the feed tank. If *c* is wide open, all the oil pumped will escape back to the feed tank. The net result is that the engine gets less and less oil as its speed increases above the normal. The fuel supply can be varied by hand independently of the governor by altering the length of stroke of the fuel pump.

(iii) Pl. **48** illustrates the method adopted in the modern Tangye heavy oil engine. The governing is effected by

PLATE 46.

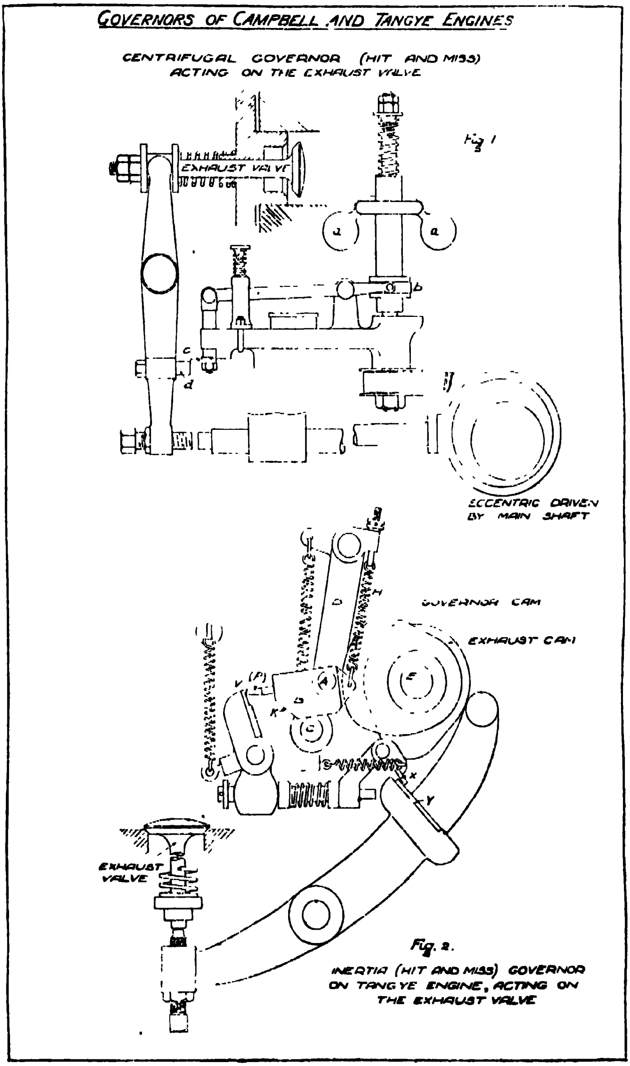

GOVERNORS OF CAMPBELL AND TANGYE ENGINES
CENTRIFUGAL GOVERNOR (HIT AND MISS) ACTING ON THE EXHAUST VALVE
EXHAUST VALVE
Fig. 1
a
a
b
c
d
ECCENTRIC DRIVEN BY MAIN SHAFT
GOVERNOR CAM
EXHAUST CAM
H
D
V
(P)
(A)
B
K
(C)
E
X
Y
EXHAUST VALVE
Fig. 2.
INERTIA (HIT AND MISS) GOVERNOR ON TANGYE ENGINE, ACTING ON THE EXHAUST VALVE

PLATE 47

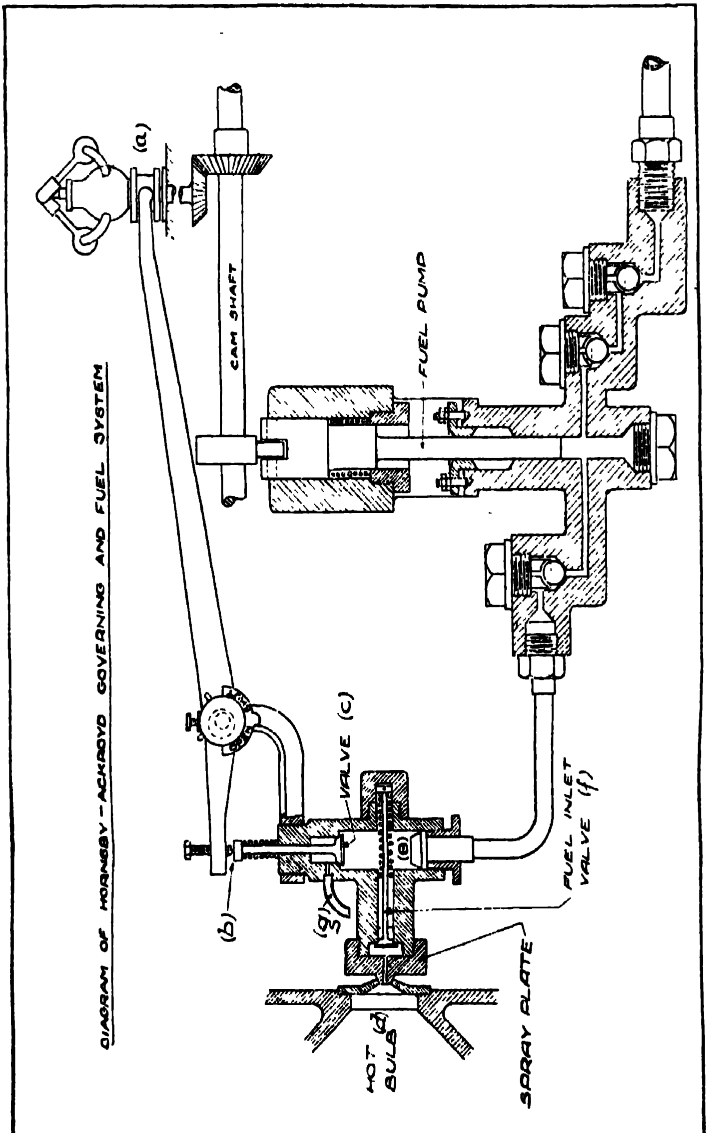


DIAGRAM OF HORNSBY-ACKROYD GOVERNING AND FUEL SYSTEM
(a)
CAM SHAFT
FUEL PUMP
VALVE (c)
(b)
(g)
(e)
FUEL INLET VALVE (f)
SPRAY PLATE
HOT BULB (d)

PLATE 48.

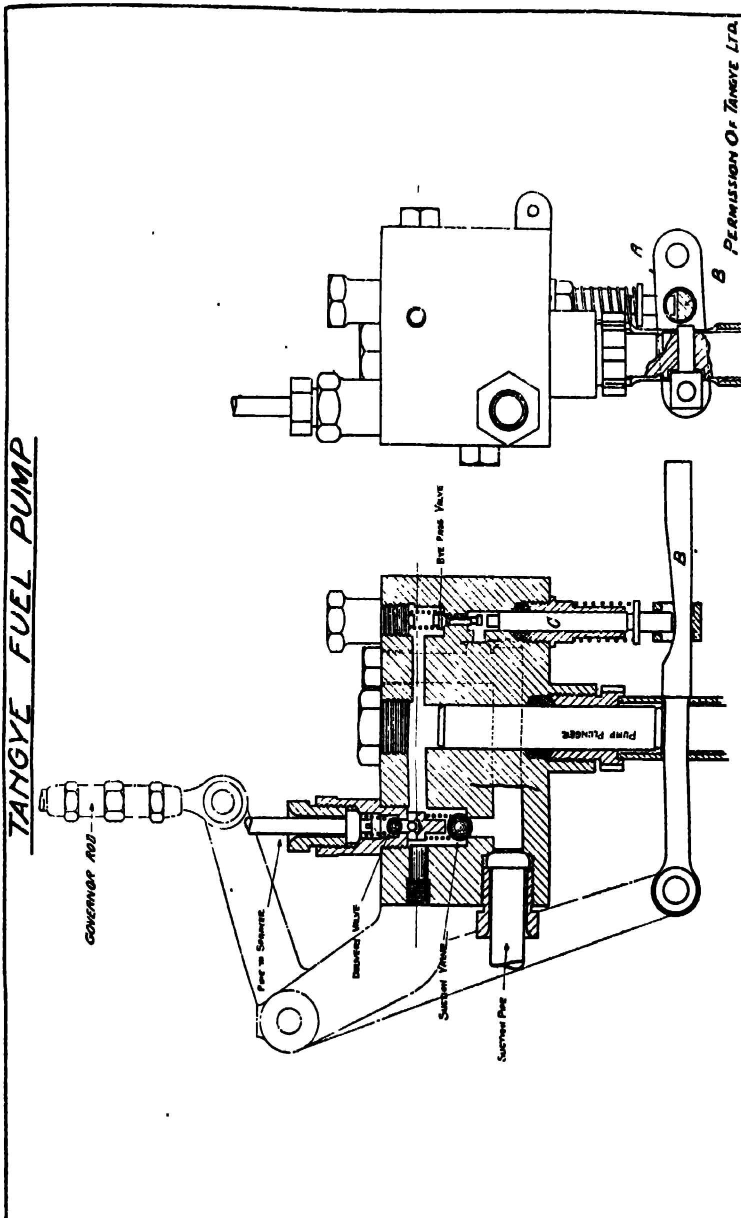
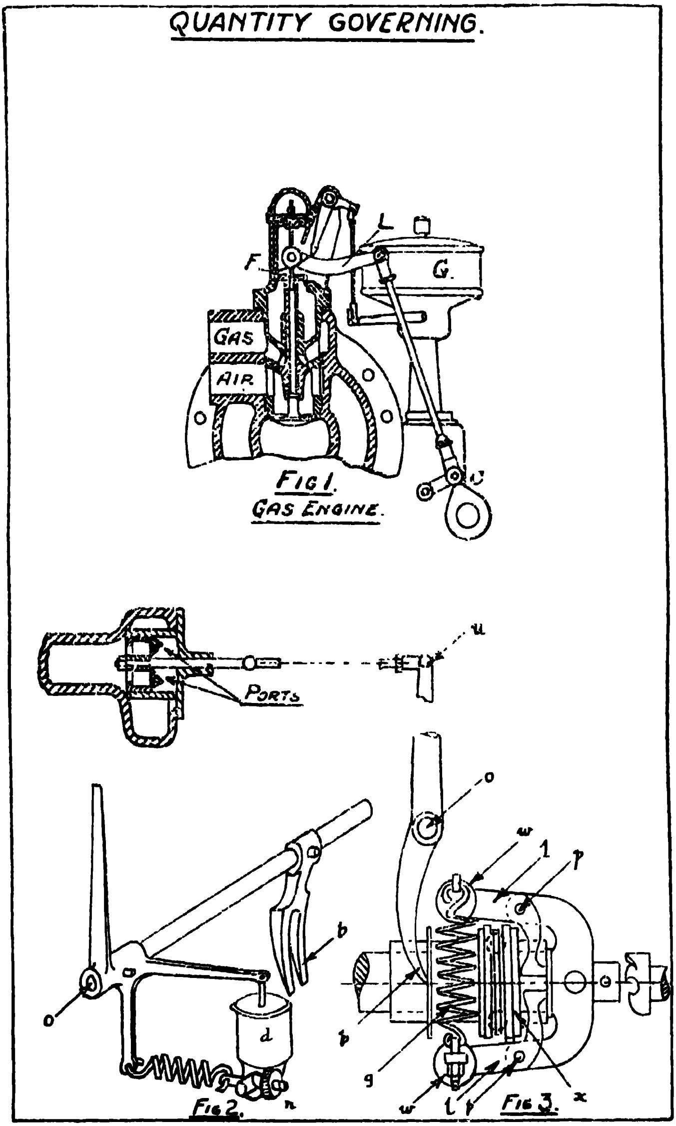

TANGYE FUEL PUMP
GOVERNOR ROD
PIPE TO SPRAYER
DELIVERY VALVE
SUCTION VALVE
SUCTION PIPE
BYE PASS VALVE
PUMP PLUNGER
C
B
A
B
C
PERMISSION OF TANGYE LTD.

PLATE 49.


QUANTITY GOVERNING.
L
F.
G.
GAS
AIR
FIG 1.
GAS ENGINE.
u
PORTS
o
w
1
p
b
o
d
n
FIG 2.
p
g
w
1
p
FIG 3.
x

varying the time of opening a spill or by-pass valve, through which the surplus oil is returned to the suction side of the pump. The time of opening of the by-pass valve is varied by the wedge *B*, and the position of the latter is determined by the governor in accordance with the speed of the engine.

The wedge *B* is hinged at one end to the bell cranked lever, which is operated from the governor, and is raised and lowered by means of the small lever *A*, through which it passes. The lever *A* is connected up at one end of the pump plunger and is operated by the latter.

As shown in the figure, the wedge *B* is in the maximum load position. In this position, there is such a clearance between the top of the tappet, *C*, and the underside of the by-pass valve, that when the lever, *A*, and wedge, *B*, are raised to the fullest extent, the by-pass valve will only be opened slightly and practically all the fuel oil will be delivered through the sprayer. When working on lighter loads, the position of the wedge will be such as to reduce the clearance between the tappet and the by-pass valve, and the latter will be opened sooner and less oil delivered to the sprayer. As soon as the by-pass valve is opened, delivery of oil to the sprayer ceases.

(iv) Pl. **75**, Fig. 2, shows an arrangement commonly used in two-stroke semi-Diesel engines in which governing is effected by altering the stroke of the fuel pump.

The fuel pump plunger, *a*, is actuated from an eccentric rod, *b*, driven off the crankshaft, *e*. The inner eccentric sheave, *d*, is keyed to the crankshaft, but the outer eccentric, *c*, is connected to the governor weights, *gg*, by the links, *ff*. If the speed increases, the weights move outwards by centrifugal force, thereby moving the outer eccentric, *c*, relatively to the inner eccentric, *d*, and thus reducing the net eccentricity, shortening the stroke of the eccentric rod, *b*, and that of the pump plunger, *a*.

The speed of the engine can also be regulated by hand by altering the stroke of the pump by means of the screw, *h*.

The fuel pump is usually provided with a safety device, in case the spray-maker should become choked. In the case of the engine in Pl. **75**, this takes the form of a diaphragm, which will burst with any excessive pressure.

Owing to a full pump stroke being given at starting (speed is too low for governor to limit stroke), too much oil is pumped in to form a mixture that will explode. It is better, therefore, at starting, to shorten the pump stroke by means of the adjusting screw, *h*, on Pl. **75**, Fig. 2.

(v) Pl. **78**, Fig. 2, shows the governing arrangement in the Mirrlees Diesel engine. The action is similar to that described in para. (iii), *f* being the by-pass valve in this case.

8. Quantity governing.—(i) In this method either—

(*a*) A combined gas and air valve is used, or

(*b*) The explosive mixture is throttled in the induction pipe.

(ii) Pl. **49**, Fig. 1, illustrates the method adopted in the Crossley gas engine. The cam, *C*, moves one end of a lever, *L*, through a fixed distance, but the distance moved through by the other end of the lever, which opens the air and gas valves, depends upon the position of the fulcrum, *F*. The fulcrum is not fixed but is moved by the governor to a position suitable for the load on the engine.

(iii) Pl. **49**, Figs. 2 and 3, show the governing arrangement on the D.V.4 Crossley petrol-paraffin engine. As the speed of the engine increases, the revolving weights, *w*, move outwards against the springs *g*, thus pushing the governor sleeve to the left through the medium of the bell crank lever *l* (with fulcrum at *p*), and the ball thrust washer *x*. This pushes the lower end *b* of the throttle valve lever (fulcrum at *o*) to the left, thus causing the upper end *u* to move to the right and reduce the throttle opening. The governor is very sensitive, and therefore a dashpot (*d*, Fig. 2) is provided to damp the movement of the governor levers. The speed of the engine may be varied by adjusting the tension on the governor adjusting spring by means of the milled nut, *n*.

72. *Lubrication of I.C. engines*

See Chapter XXXIII. Service Lubricating Oils are given in Table ZA, page 604.

1. Primarily, the object of a lubricant is to keep the rubbing surfaces apart, and to build up a film between them which under all conditions of speed, temperature, and pressure, will not be squeezed out.

So far as engines are concerned (both steam and I.C.) the problem falls roughly into two distinct divisions, *viz.*, *Cylinder Lubrication* and *Bearing Lubrication.*

2. Cylinder lubrication.—It is important to avoid giving the cylinder too much lubrication, and the best method of applying it is undoubtedly by a mechanical force feed lubricator giving separate controllable feeds to four or even eight (in large engines) points on the cylinder where the wear is greatest. This method is almost invariably used in both open and enclosed type engines of moderate size (say) from 100 H.P. upwards.

The three essential properties of an oil for cylinder lubrication are :—

i. *High flash point.*

ii. *Vaporized oil* must leave as *little residue as possible* (even the best mineral oils leave some carbon deposit).

iii. *Fairly high viscosity.*—If an oil too light in body is used it will break down under the high temperature and lose its power of forming a film or "*oil seal*" round the piston and will work too freely past the piston rings into the combustion space, causing carbon deposit and a smoky exhaust. It will also be squeezed out from between piston rings and cylinder and excessive wear will result. If the oil is too heavy it will fail to spread freely, forming only a partial film and piston friction will be excessive.

In either case, leakage of gases past the rings will occur on the compression and explosion strokes with consequent loss of power.

Compound oils, excellent for external lubrication purposes generally, are quite unsuitable for the internal lubrication of any engine (steam or I.C.) since the animal or vegetable constituents become carbonized by the heat, and, in I.C. engines, tend to produce pre-ignition troubles.

Moreover, when animal or vegetable oils are churned up with a little water they saponify and form a thick lather which tends to choke the small pipes and oilways of a forced lubrication system. It is, therefore, always preferable to use a *pure mineral oil* for the *lubrication of enclosed engines* in which circulation is maintained by a pump of any kind.

The heavy high flash point oils, eminently suitable for cylinders with sight feed or force feed lubrication, are not suitable for *splash* lubrication which is commonly employed in small enclosed type engines, since their great viscosity prevents them from readily dissolving into the oil mist or fine spray which is relied upon for lubricating the cylinder. In this case, therefore, to satisfy the conflicting requirements of cylinders and bearings it is necessary to compromise by using a somewhat thinner oil and take the chance of increased carbon deposits. Special oils are on the market for this purpose. Incidentally a fairly low viscosity and specific gravity give a better result for a circulating oil, as it more readily separates from water, dirt, and other foreign matter. In the case of petrol engines, which invariably have splash lubrication for the cylinders, the situation is modified somewhat by the dilution of the lubricating oil with petrol, which results in a

decrease in viscosity of the oil. In heavy oil engines this dilution is not so liable to occur and the lubricating oil is more likely to increase in viscosity with use.

3. **Bearing lubrication.**—The problem to face with main bearings, big ends and small ends, is that due to large pressures tending to break down the oil film. Careful examination of a badly worn crankshaft will indicate, however, that the relatively high bearing pressure in the power stroke causes far less wear than the less intense but longer sustained pressure due to inertia and centrifugal force. This shows that a film of oil can hold a heavy load for a short period, but is more likely to break down under sustained pressure. Once the film has broken down, relatively little pressure is sufficient to cause abrasion. Very little trouble is experienced with the bearings in four-stroke cycle engines, as the pressure on the journals is frequently reversed and allows a constant oil film to be maintained.

In *open type* engines the crankshaft journals are either ring-lubricated or fed by gravity from a tank. The big end is fed by means of a centrifugal oiling ring attached to the crankshaft. The small end is fed in the same way as the cylinder. A forced feed is arranged to deliver oil through the cylinder walls at a point where it will coincide with a vertical groove milled in the surface of the piston. From this groove a drilled hole leads into the centre of the gudgeon pin whence, by a radial hole at the centre, the oil reaches the actual bearing surface of the pin.

Except in the case of very small high speed engines in which splash lubrication is relied upon, all the bearings of *enclosed* engines are force fed under a pressure of 10 to 40 lb./sq. inch.

In ring-lubricated and gravity fed bearings a lighter oil with a lower flash point than that required for the cylinders will usually be quite satisfactory and much cheaper. As a general rule, however, it is inconvenient to use two different grades of oil, even where the bearing and cylinder systems are quite separate.

In enclosed engines the heat radiated from the piston and cylinder walls results in the bearing temperatures reaching anything from 90° to 160° F.

For normal running the temperature should not be allowed to go above 140° F. or the oil will quickly oxidize and its useful life will be short.

4. **General remarks.**—There is no space to deal with the lubrication of other details such as camshafts, valves, &c., but when taking over an engine it is necessary to make sure how these components are lubricated.

In small engines, the camshaft bearings, governor gear and

valve gear are provided with oil holes for oil-can lubrication by hand.

In large engines all these parts are usually fed from the main oil circulating system.

When an engine has been at rest for some time the oil films on the various working parts have more or less completely broken down. They have been squeezed out by the sustained pressure due to the weight of the parts and a certain amount of metallic contact takes place. As a result, the starting effort of an engine is very considerable and the static coefficient of friction may quite easily approach that of solid friction. Further, the increased viscosity of the lubricating oil when cold will cause the power lost in friction to continue to be excessive until the oil has warmed up.

Perhaps the most frequent cause of wear in petrol engines is the running at starting, when the old oil has drained away from the various parts and before the new supply of cold and relatively thick oil has had time to reach them. For this reason, as well as others, engines should invariably be started with as small a throttle opening as possible, and run light for a few minutes at low speed until the oil has warmed up and can circulate freely. The practice of racing an engine at starting to warm it up cannot be too strongly deprecated.

5. Examples of lubrication systems likely to be met with in the service.

(i) *Open type horizontal engines.*—(*a*) *Piston and cylinder.*—In small engines the following devices are employed, Pl. **50**, Fig. 1 :—

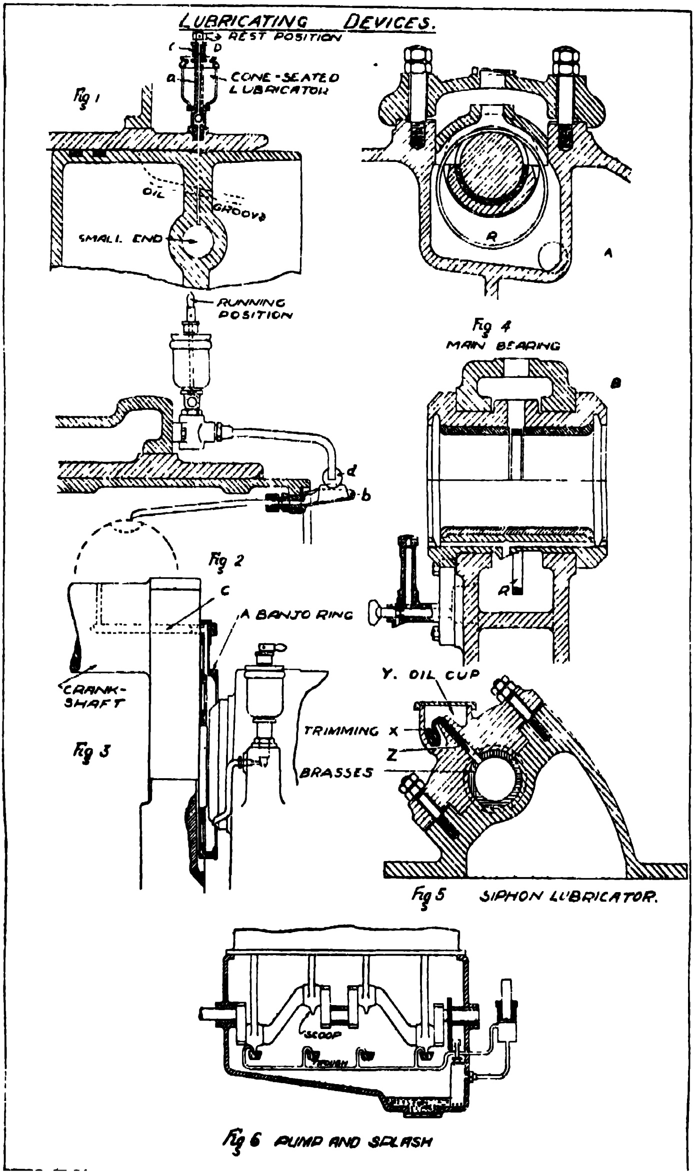
A sight-feed lubricator is screwed into the top side of the cylinder near the open end. The oil path from the lubricator is through the cylinder liner on to the top of the piston, on which are oil grooves. The lubricator is provided with a needle valve, *a*, which is lifted by turning the hinged piece, *b*, upright. The screw, *c*, adjusts the lift of the needle valve to suit varying rates of drip. It should be adjusted to keep the piston lightly oiled.

These lubricators require watching, as they are somewhat unreliable. When not required to feed, the needle valve is dropped.

(*b*) *Gudgeon pins.*—One method in use is shown on Pl. **50**, Fig. 1. Some of the oil delivered to the top of the piston is led through a small hole in the piston, directly above a conical passage in the top of the small-end bearing into which the oil drips.

A modification of the above method is shown on Pl. **50**, Fig. 2. Here a separate sight-feed lubricator is screwed into the end of the cylinder. It delivers oil to a disc, *d*,

PLATE 50.


LUBRICATING DEVICES.
REST POSITION
C
D
a
CONE-SEATED LUBRICATOR
Fig 1
OIL
GROOVE
SMALL END
RUNNING POSITION
d
b
Fig 2
C
A BANJO RING
CRANK-SHAFT
Fig 3
A
Fig 4 MAIN BEARING
B
R
Y. OIL CUP
TRIMMING X
Z
BRASSES
Fig 5 SIPHON LUBRICATOR.
SCOOP
TROUGH
Fig 6 PUMP AND SPLASH

which is free to rotate on its axis; the oil is collected by the catcher, *b*, which is fixed to the piston, and conveyed through a pipe, attached to the piston, through a conical hole in the small-end bearing.

(*c*) *Big-end bearing.*—Pl. **50**, Fig. 3, shows the usual method. A *banjo* oiling ring, A, is fixed to and turns with the crankshaft. A sight-feed lubricator delivers oil to it. Oil delivered to the ring takes up a position on the rim owing to centrifugal force, and is forced through the passage, C, to the bearing.

(*d*) *Crankshaft main bearings.*—Pl. **50**, Fig. 4, shows the usual (oiling ring) method. The reservoir is filled with oil; the ring, R, supported on the shaft at a point where a groove is cut in the top brass, revolves on the shaft, and picks up oil which is delivered to the bearings.

These lubricators should always be examined on starting the engine, as the rings are liable to stick at starting.

(*e*) On some engines the siphon lubricator may still be met with. Pl. **50**, Fig. 5, shows one.

A trimming, X, consisting of a few strands of worsted, siphons the oil out of the cup, Y, down a tube, Z, and into the bearing. The end of the trimming in the tube must be lower than the level of the oil in the cup. A piece of wire is twisted up in the trimming, to form a handle and to regulate the distance the trimming is inserted into the tube. A trimming must be sufficiently loose in the tube not to form a plug. When not required to feed, the trimming is taken out of the tube and placed in the cup.

Siphon lubricators are absolutely reliable when properly made and adjusted.

(ii) *Enclosed type vertical engines.*—(*a*) *Splash lubrication.*—Oil is supplied to the crankcase to a given level. The connecting rods dip into and splash the oil to all parts of the engine. Oil is renewed at intervals to maintain the oil level in the crankcase.

This method is only used for small single-cylinder engines.

(*b*) *Pump and splash lubrication.*—Pl. **50**, Fig. 6. Oil is supplied to the crankcase to a given level. It is drawn from a sump by a pump through a strainer, and delivered to troughs above the oil level, which are thereby kept full. The connecting rods dip into the troughs and splash oil to all parts of the engine. An indicator should be fitted to the pump to show that it is functioning. This system is commonly met with.

(*c*) *Petroil lubrication* (applicable to two-stroke petrol engines only).—Petrol and oil mixed are supplied to the carburettor from the supply tank, and the oil finds its way to all

working parts along with the mixture. This is a much better method than it sounds, and is very simple. The proportions of oil to petrol vary a good deal and makers' instruction books should be consulted, if experience is not available. A quarter of a pint to a gallon of petrol is about right. Too much oil invariably fouls the sparking plugs; too little leads to excess wear or piston seizure.

Always mix the oil and petrol in a separate can and shake well before adding to the fuel tank. They do not mix sufficiently if added separately to the tank.

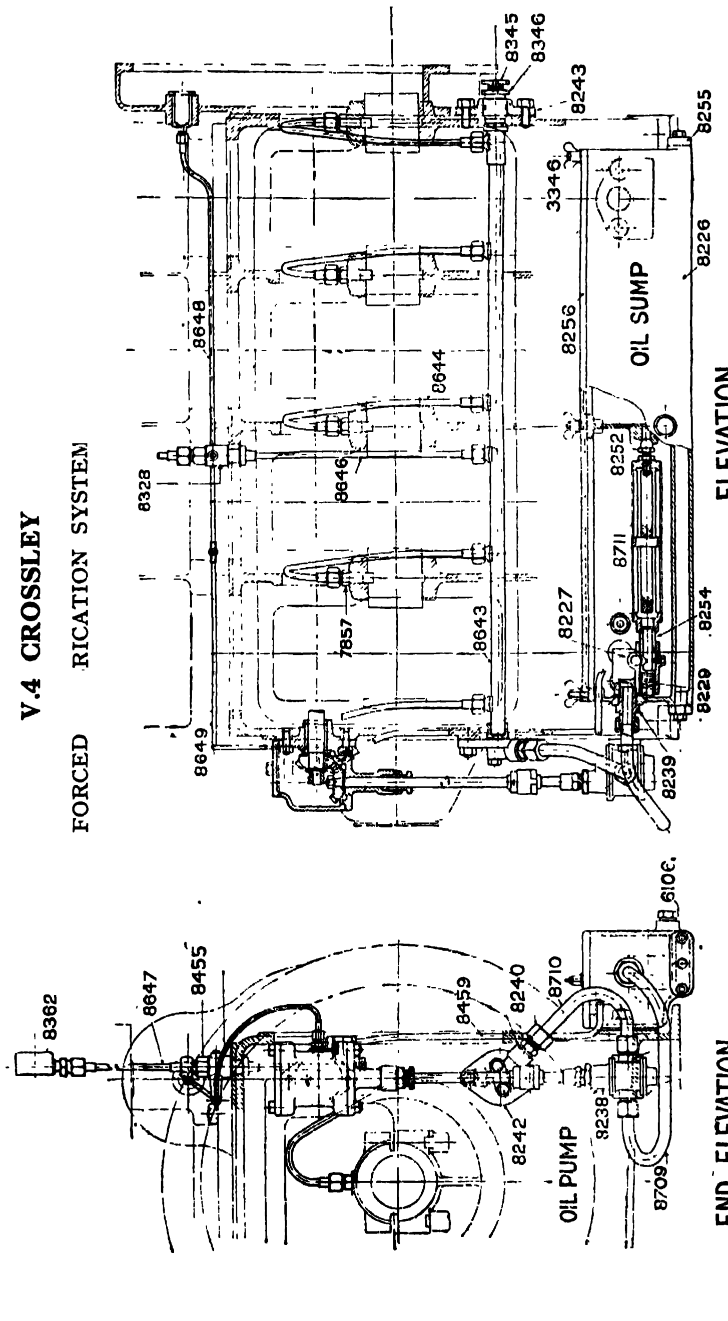
Where the main crankshaft bearings are plain (instead of ball or roller) greasers or separate oil cups are often provided in addition to the petroil system. This assists lubrication at the points where the petroil system is least satisfactory, and it helps to seal the bearings against air leaks into the crankcase on the suction stroke.

(*d*) *Forced lubrication.*—Pl. **51** illustrates the arrangement on the D.V.4 Crossley Petrol-Paraffin engine. The lubrication of the engine is automatic throughout and is effected by a gear pump (8238) driven by bevel wheels from the camshaft. The lubricating oil is drawn from a sump (8226) outside the bottom of the crank chamber. The oil passes from the crankchamber to the sump and then through two oil strainers (8711) and along the suction pipe to the pump (8238), from whence it is delivered under pressure to the main bearings and big end bearings through oil passages in the crankshaft. The cylinders and gudgeon pins are lubricated by splash. Splasher guards prevent an excessive amount of oil from being thrown by the cranks into the cylinders. A pressure gauge (8362) registers the pressure of the lubricating oil, which need not exceed 5 lb./sq. inch. When the oil is hot or thin less pressure will be registered than when the oil is cold or thick. The oil pressure may be regulated by means of a spring loaded relief valve (8345). After supplying the bearings with oil some of the oil flows to the end camshaft bearing and to the magneto wheel shaft bearings, the remainder passing through the relief valve to the bottom of the crank chamber back to the sump. The oil sump is so arranged that cold water may be circulated through a passage (8255) under the oil to keep it cool.

The forced lubrication system is so arranged that it can be applied to the gudgeon pin, if necessary (as it may be in hot climates).

The oil strainers should be removed weekly for cleaning. They can be removed, one at a time, while the engine is running. The crank chamber and oil sump should have all dirty oil cleaned out every two to four weeks if the engine is in regular work.

PLATE 51.



V.4 CROSSLEY

FORCED RICATION SYSTEM

A small quantity of oil should be added each day before starting, to keep up the level to the place marked inside the left-hand sump cover.

It is absolutely necessary for the oil strainers to be completely covered with oil, otherwise air may be sucked in instead of oil and the bearings thereby ruined.

When the engine is first started, or when re-starting after the lubricating oil pump or any of the oil pipes have been dismantled, such as after an inspection of the bearings, the engine should be turned round slowly by hand until the lubricating oil pipes are full of oil and until the oil is actually delivered to the bearings.

Also a few ounces of lubricating oil should be poured into the cylinders through the test cocks to ensure that the cylinders start with some lubrication.

Should the engine be started and no pressure be shown on the pressure gauge, the engine should be stopped and the cause of the absence of pressure ascertained.

Pl. **52** shows the bearing lubrication system on the modern enclosed type of Davey Paxman heavy oil engine. Its resemblance to the Crossley system will be noted and the instructions given above for that system generally apply. The gudgeon pins are, however, normally fed through a drilled connecting rod. The position occupied by an oil cooler (when fitted) is shown.

The oil pressure should be maintained at 15 lb./sq. inch (minimum safe, 10 lb.). Use excess pressure only if required after fitting new parts or to cool any part which may be heated unduly. The pressure may be higher at starting but should be adjusted to the correct figure when oil is warm.

Before starting, circulate oil through system and raise pressure to 5 lb./sq. inch at least by means of hand pump provided. Also work pump for a minute after shutting engine down.

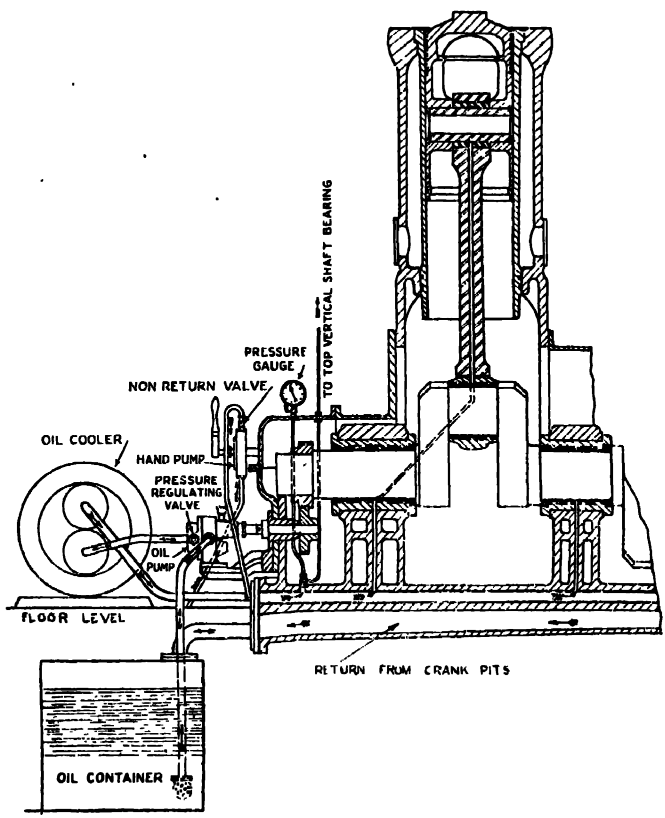
The cylinder lubrication in these Davey Paxman engines is by splash in the case of small engines and on large engines by mechanical force feed lubricators. Pl. **53** shows the type of mechanical lubricator fitted to the 120 B.H.P. engine in the E. & M. School, S.M.E.

The eccentric rocks the lever carried in the bearing (S.35), and through the medium of the ratchet pawl (S.34) and ratchet wheel (S.32) revolves the pump lever cam (S.25) and the distributor cam (S.21). The lubricator operates in the following manner :—

Starting from the position shown in the side section, the plungers (S.28) are delivering oil through the distribution valve (S.17) and lower tubes (S.18) to the delivery pipe connection (S.13) at the back of the lubricator.

PLATE 52.

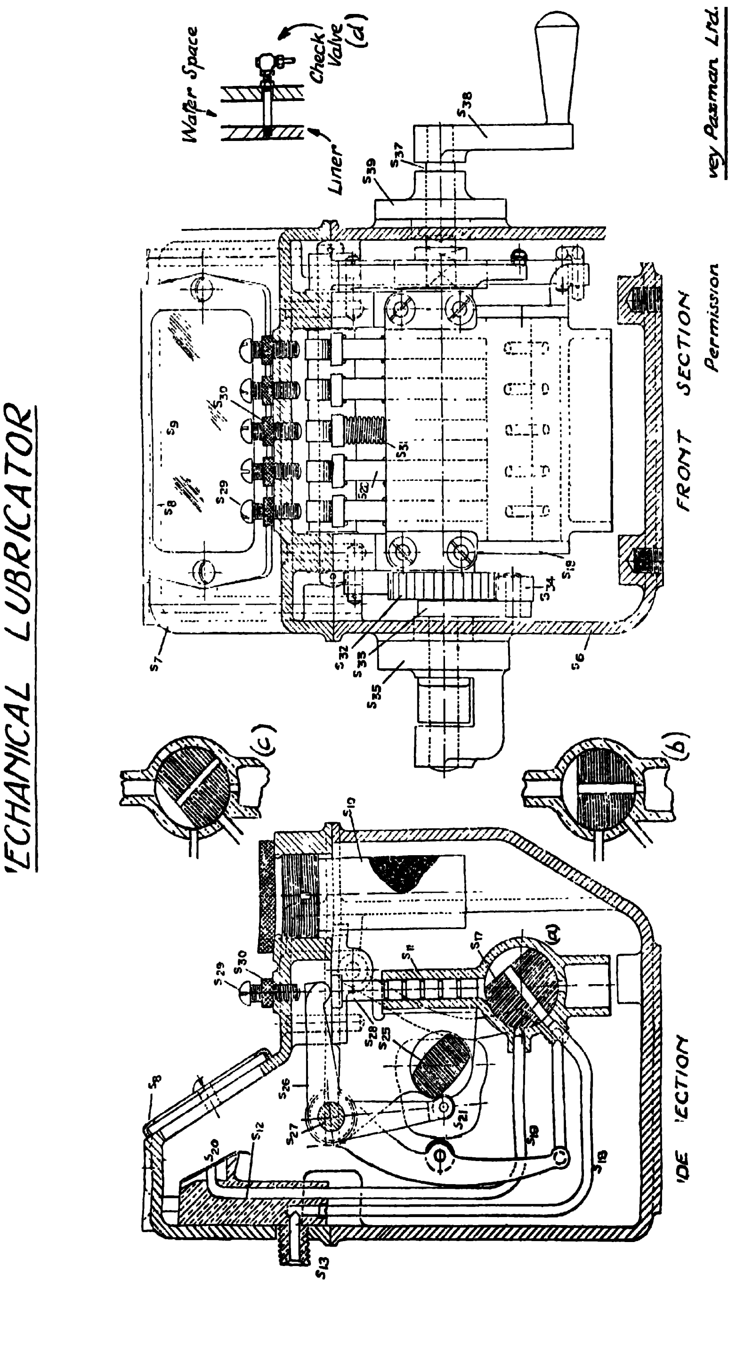
FORCED-FEED LUBRICATING SYSTEM



SECTIONAL ELEVATION SHOWING LUBRICATING OIL PRESSURE SYSTEM AND UNDERGROUND SUPPLY TANK FOR CIRCULATING OIL TO MAIN, BIG AND SMALL END BEARINGS

Permission of Davey Paxman & Co., Ltd

PLATE 53.


'ECHANICAL LUBRICATOR
FRONT SECTION
'IDE 'ECTION
Water Space
Liner
Check Valve (d)
(a)
(b)
(c)
Permission
vey Paxman Ltd.

Before the plungers are allowed to rise, the valve has taken up its mid-way or vertical position (Fig. *b*), thus allowing the plungers to draw oil from the well of the lubricator. While the plungers are still at the top, the valve (S.17) takes up the angular position shown in Fig. *c*, thus connecting the plungers with the upper tubes (S.19) which lead to sight drips (S.20). To regulate the quantity of oil delivered, the set pins (S.29) are screwed in or out, thus altering the stroke of the plungers.

When first starting up the engine, the lubricator handle (S.38) should be pushed endwise into engagement with the pump spindle and turned until oil is seen to flow freely from all the sight drips. This ensures that all the pumps are in working order. It is not positive evidence that all the feed pipes are delivering oil to the engine parts but obstructions in these short lengths of pipe are unlikely.

In this respect the type is inferior to other designs of mechanical lubricator in which the quantity of oil passing can be clearly seen and measured.

A lubricating oil connection to the cylinder, with check valve, is shown in Pl. **53**, Fig. *d*.

(iii) *Open type vertical engines.*—The Davey Paxman engine in the E. & M. School is of this type (*see* Pl. **83**), and the lubricating arrangements are somewhat different from those outlined above. The crankshaft and camshaft bearings are ring-oiled and the cylinders small ends and big ends are force fed by a mechanical lubricator similar to that described above. The camshaft and governor gears and exhaust valve cams and guides are in oil baths, and small lubricators are provided for the governor and eccentrics.

Other parts are oiled by hand.

6. **Faults in lubrication systems.**—i. If the oil tell-tale or pressure gauge is correctly placed on the end of the line and is registering the right pressure, it is almost certain that oil is reaching the important bearings. Accidental obstruction in the oil passages on the delivery side of the oil pump is most unlikely. The pressure is usually sufficient to clear such obstruction, except in the case of pieces of rag, fluff, &c., left inside the engine by carelessness when overhauling.

ii. If no oil pressure is indicated, the most likely causes are :—

(*a*) No oil in the sump, or not enough.

(*b*) Oil pump empty ; needs priming. This is very common after overhaul, with the gear type of oil pump.

(*c*) Serious air leak on suction side of pump. Most oil pumps now are submerged in the sump to avoid this trouble and obviate priming.

If insufficient or unsteady oil pressure is indicated, the most likely cause is a choked filter on the suction side of the pump.

These symptoms may also be due to insufficient oil in the sump. Filters must be cleaned and the oil level inspected regularly.

It is uncommon to have faulty ball valves in the plunger type of oil pump. Worn plungers are also uncommon and are usually only found in old engines.

iii. Excess pressure in forced lubrication systems is usually noticed after starting a cold engine and is due to the thickness of the cold oil. As soon as the engine is warmed up the oil pressure should fall to normal. If it remains above normal a thicker oil may have been put in the crankcase or there may be an unusual obstruction in the oil ways somewhere on the delivery side of the tee to the oil gauge. In some engines a relief valve is fitted to the pump to limit the pressure.

73. *Air filters for I.C. engines*

When an I.C. engine is working in a dusty situation it sucks in particles of grit which form a grinding paste with the oil causing wear, and some of the grit is deposited on the cylinder head and piston and forms a large portion of the "*carbon*" deposit. If the dust can be prevented from entering the engine there will be less wear, less frequent decarbonizing, lower oil consumption, lower maintenance charges and a longer life for the engine.

An air filter is therefore an essential feature on an I.C. engine when it is to be used in a dusty situation, such as a motor-car in desert country, or on an excavator. It is a very desirable feature on an engine wherever it operates, and the time cannot be far distant when it will become a standard feature.

Tests have been carried out on motor-car engines with and without air filters in identical situations. These have shown that the wear in the engine with an air filter varies from 60 to 90 per cent. less than in the one without, and the oil consumption is reduced by 40 per cent.

Air filters have the added advantage in the case of large I.C. engines in a power station, of silencing the air intake which might otherwise be obnoxious. Similarly on automobiles they eradicate the hissing of the carburettor.

The desirable features in a filter for an I.C. engine are :—

(1) That it shall stop all dust detrimental to the engine.

(2) That it shall not affect the performance of the engine, *i.e.* the volumetric efficiency should be unaltered by ensuring a low water gauge reading across the filter.

(3) That it shall need as little cleaning and attention as possible.

As regards (1), it is the largest particles of grit which do the damage and it is probably unnecessary to have a filter which is nearly 100 per cent. efficient. Various makers, however, claim efficiencies of over 99 per cent., and still manage to provide a reasonably priced filter which fulfils the other conditions.

The effect on volumetric efficiency can be tested by taking a slight spring diagram with and without the filter. The water-gauge reading across any filter, at any rate when new, is usually quite small, not exceeding an inch or two, and is therefore quite negligible, not exceeding the ordinary variations in the barometer.

If the filter chokes up, however, this water-gauge reading will rise, and reduce the volumetric efficiency and hence the output of the engine; this happens sooner or later with nearly all filters and various claims are put forward by different manufacturers with regard to the self-cleaning properties of their filters.

Nearly all manufacturers of air filters make up some slight variation of their usual design to suit I.C. engines and air compressors, and it should be remembered that the filter should be designed to pass the air at the maximum rate at which it will be sucked in, which will be a higher figure than the average as worked out from the swept volume.

Assuming that the piston speed is sinusoidal and that the mean air requirement is S. cu. ft. per min., a single cylinder engine or compressor will require a filter to pass 3·14 S. per min. a twin cylinder 1·57 S. and a four cylinder 1·15 S.

There are a large number of types of filter for I.C. engines on the market.

The *Vokes* and *Zenith* filters are of the fabric type. Louvres on the casing are designed to extract the heavier particles, and the makers rely on the vibration of the engine to dislodge most of the fine dust settling on the fabric so that it does not choke up too quickly.

Other types are the *Heenan* (Heenan and Froude, Ltd.), the *Visco* (Visco Eng. Co., Ltd.) and the *Ventex* (Ozonair, Ltd.).

74. *Cooling of I.C. engines*

1. The high temperatures attained inside the cylinders of I.C. engines necessitate cooling arrangements, otherwise cylinder lubrication would be impossible and the mechanical expansion and distortion due to thermal stresses would be excessive. On the other hand, the hotter the engine the higher the thermal efficiency and, within limits, the lower the friction losses.

In engines of moderate size the cylinder liner and cylinder head are cooled by providing them with water jackets through which water is circulated. In very large engines the pistons, exhaust valves and exhaust pipes are water cooled as well, but engines of such a size as to require these extra cooling arrangements are not likely to be met with in the service.

In practice there is a tendency on the part of engine drivers to overcool their engines.

The temperature of the cooling water at exit should not be less than 100° F. nor greater than 140° F. The best figure for large engines is from 120° to 130° F. and for small ones 130° to 140° F. (excluding road vehicle engines in which temperatures of 170° to 190° F. are permitted to keep down the weight of cooling water required).

It should be noted that the smaller the engine the closer does the average temperature of the cooling water approach the maximum spot temperature.

In estimating the quantity of water required it may be assumed that 30 per cent. of the heat value of the fuel consumed is removed by the cooling water.

Consider an engine taking 0·5 lb. of fuel per B.H.P. hour of calorific value 19,000 B.Th.U. per lb. Then the cooling water must remove $19{,}000 \times 0{\cdot}5 \times 0{\cdot}3 = 2{,}850$ B.Th.U. per B.H.P. hour at full load. Assuming temperatures of 60° and 130° F. at inlet and outlet respectively, then $2{,}850/70 = 40{\cdot}7$ lb. $= 4$ gallons per B.H.P. hour are required to flow through the engine when running continuously at full load. This is the minimum quantity required in cases where the inlet and outlet temperatures can be maintained at the figures quoted. When, as is usually the case, a stored quantity of water is circulated, with cooling arrangements, it will not always be practicable to keep the inlet temperature down to 60° F., and it is therefore advisable to base calculations upon double the rate of flow assumed above.

In installations of moderate size the radiation and evaporation from the storage tanks are sufficient for cooling purposes. In large installations, cooling ponds, cooling towers (Pl. **55**, Fig. 1) or mechanical coolers (Pl. **55**, Fig. 2) are frequently employed to keep down the storage capacity to reasonable dimensions. In marine engines and also in land engines installed near the sea or a river, a cooler on the principle of a steam surface condenser is sometimes used.

In motor vehicles and portable petrol generating sets the quantity of circulating water is necessarily small and the rate of cooling is accelerated by a radiator and a fan. (In the case of a vehicle the rate of cooling is still further increased when in motion.) This method is used occasionally in stationary plant of moderate size for special reasons (*see* Pl. **88**).

2. Cooling systems.—There are four main cooling systems :—

i. Thermo-siphon circulation.
ii. Pump assisted thermo-siphon circulation.
iii. Gravity feed with pump return.
iv. Forced circulation.

i. *Thermo-siphon circulation.*—Pl. **54**, Fig. 1, shows an engine cooled on the thermo-siphon principle. Circulation is effected by hot water ascending in the outlet pipe, A, and being replaced by cool water entering through the inlet pipe, B. The force promoting this circulation is proportional to the difference in weight between the column of hot water of height X and the column of heavier cool water in a similar pipe of height X. From this it follows that the higher the cooling tank is placed above the engine, the quicker will be the circulation, provided water friction is not increased.

In any case, the bottom of the cooling tank should not be lower than the centre line of the cylinder.

The cooling system must always have sufficient water for the outlet, G, to the ascending pipe to be covered ; otherwise, circulation will not take place. The length of piping should be kept to a minimum and its diameter should not be less than that provided for on the engine flanges. Sharp bends in all pipes and horizontal runs between the engines and tank tend to cause friction in the system and to impede the circulation ; they should be avoided or kept to a minimum. The hot-water outlet pipe should slope upwards throughout its length. In temperate climates from 30 to 40 gallons per B.H.P. is usually found sufficient for normal running, but if the engine runs at full load continuously for long periods a larger quantity should be provided.

The shape of the cooling tanks is not important but they are usually supplied of cylindrical form. It is an advantage when a number of tanks is supplied if they vary slightly in diameter so that they can " nest " one in the other for transport purposes. A convenient average size is 8 feet high by 4 feet diameter which has a capacity of about 600 gallons, sufficient for a 15 B.H.P. engine in a temperate climate. In larger engines a battery of such tanks should be used, connected in parallel by large diameter pipes top and bottom.

The function of the cooling tanks being to cool the heated water so that it can be used again as cool inlet water, they must naturally be placed *outside* the engine room and so situated that they are well ventilated. There is little probability of damage to the tanks themselves due to frost.

As loss by evaporation will occur, a ball-cock, H, should be fitted to provide make-up water, which is preferably led into the bottom of the tank through K.

PLATE 54.

WATER-COOLING SYSTEMS.

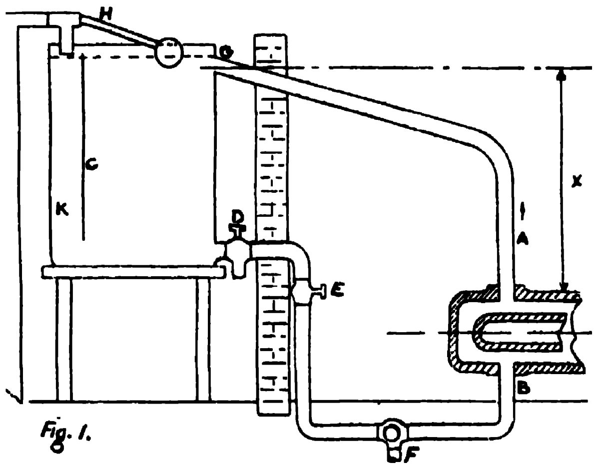


Fig. 1.

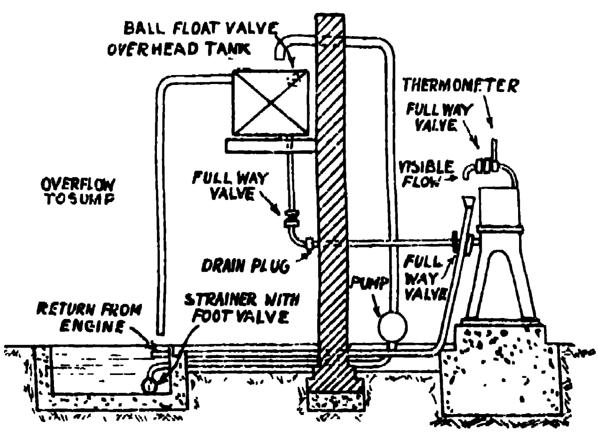


Fig. 2. Gravity Feed, Pump Return.

PLATE 55.

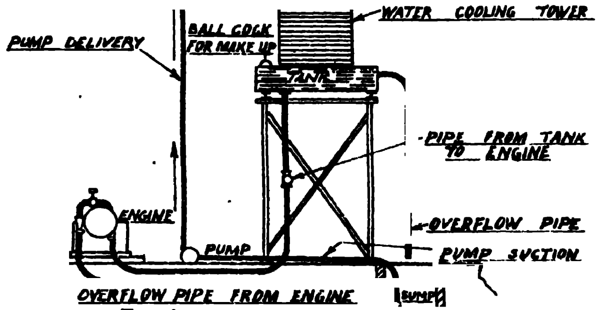


Fig. 1.

DIAGRAMMATIC ARRANGEMENT OF COOLING TOWER.

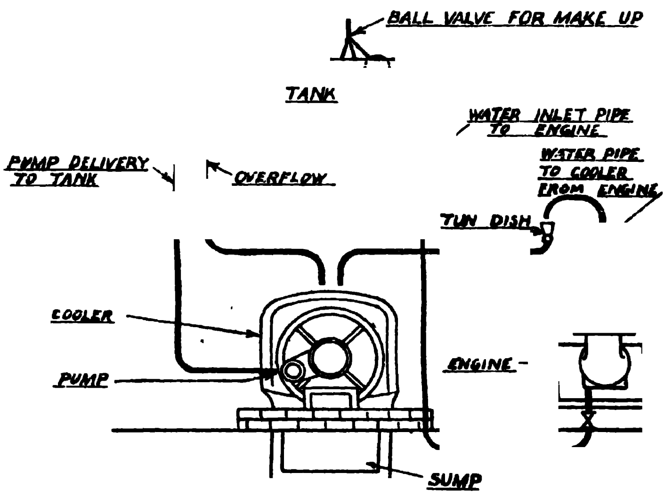


Fig. 2. GRAVITY FEED, PUMP RETURN WITH MECHANICAL COOLER

The following cocks and valves are required in the cooling system :—

Inside the engine house : A drain-cock, F, at the lowest point, to empty the cylinder jacket for cleaning purposes or in frosty weather. A full-way valve, E, to regulate the rate of circulation to suit the load.

Outside the engine house : A three-way cock, D, either for draining the tank or for shutting off the supply when it is desired to drain the remainder of the system through F, is a convenience but not a necessity.

ii. *Pump assisted thermo-siphon.*—In this system which is common on small engines up to (say) 50 B.H.P., an engine-driven pump is used to help the circulation. A storage capacity of 20–25 gallons/B.H.P. is sufficient with this system.

In cases where the cooling tanks are necessarily a long way from the engine, a pump may be necessary with quite small engines.

iii. *Gravity feed with pump return.*—This is the most common system with engines of moderate size (*see* Pl. **54**, Fig. 2).

Taking a multi-cylinder vertical engine as the most common type, the supply is gravity fed to a distributor from which connections are made to each cylinder. The water passes up the space round the cylinder liner and thence to the cylinder cover from which it is carried away to a main discharge pipe. On each of the outlet pipes a cock is fitted to enable the quantity of water to be adjusted in order to maintain an equal temperature in all cylinders. The quantity of water required should also be adjusted to suit the load, but it is not practicable to do this unless the average load can be fairly accurately predicted for a period. If the flow is adjusted to keep the outlet temperature at 130° F. at maximum load, the temperature will clearly be less than desirable at lower loads. Thermometers should be provided at each cylinder outlet pipe and, wherever possible, each outlet pipe should be arranged with an open end so that the water flows visibly into a funnel (or tun-dish) on the discharge pipe. This affords a ready means of seeing at once that the system is in working order.

It is usual to instal a storage tank large enough to hold at least half an hour's supply of cooling water (4 to 5 gallons per B.H.P.), and it is an advantage to provide a sump into which the cylinder outlet water discharges and from which the circulating pump raises the water up to the storage tank again. This will prevent flooding the engine room if the engine-driven pump breaks down. The sump should be large enough to store the cooling water outlet for about 20 minutes,

which should give the attendant time to notice and rectify a faulty pump, or to start up an auxiliary independently driven pump, which should always be provided in electric power stations.

It is also necessary to maintain the circulation of the cooling water for about 20 minutes after shutting down the engine, otherwise the water in the jackets will boil and excessive quantities of lime will be deposited. This not only reduces the water space but forms an insulating lining which reduces the rate of heat flow to the cooling water, and if permitted to take place often it will ultimately result in a cracked cylinder or cylinder head. It is advisable to flush the water spaces occasionally, and if the water is hard, to add 1 lb. of common washing soda to 250 gallons. In large power stations it is often found worth while to instal water softening plant.

iv. *Forced circulation.*—This system is used when it is impracticable to instal the storage tanks high enough for gravity feed. In this system if the engine-driven pump breaks down, the engine is put out of action, and therefore an auxiliary independently driven pump is essential to ensure reasonable continuity of running and to enable the circulation to be continued for a time after the engine has been shut down.

In marine engines it is sometimes the practice to pass seawater through the jackets for cooling purposes. This appears to be satisfactory providing that the water is well filtered and that the outlet temperature is not allowed to exceed 100° F.

In the case of pumping plants, part of the pumped water from the rising main is sometimes by-passed through the engine and run to waste. This is a useful method for field sets.

3. **Cooling systems in the Tropics.**—Thermo-siphon cooling as provided by manufacturers with standard equipment may not always prove satisfactory in hot climates owing to :—

(i) Insufficient radiation at the tanks.
(ii) Too slow a circulation.

(i) Can be improved by—

(*a*) Increasing size of storage tanks some 50 to 100 per cent. above that required in temperate climates.

(*b*) Using shallow tanks to give as great a surface as possible for a given capacity. If shallow tanks are used they should be fitted with division plates to improve the circulation.

(*c*) Siting tanks in the shade and to allow free circulation of air. Radiation might be improved with a fan.

(ii) Can be improved by ensuring that—

(*a*) Large pipes with short runs are used with as few bends as possible.

(*b*) Outlet pipe from engine rises at once to the cooling tanks.

(*c*) The tanks are sited as high as possible.

In general, thermo-siphon cooling can be made to function satisfactorily in the tropics with four-stroke engines up to 20 B.H.P., provided the above conditions are complied with. For larger sizes than this, and for all but very small two-stroke engines, some form of forced circulation may be required, working in conjunction with a small cooling tower or mechanically operated cooler. (*See* Pl. **55**, Figs. 1 and 2.)

75. *Exhaust silencers*

1. If the products of combustion are allowed to escape direct to atmosphere when the exhaust valve is opened, the resulting noise is objectionable. It is caused by the rapid expansion of the combustion products from the cylinder, which leave it at about 35 lb. per square in. pressure and expand down to atmospheric pressure very rapidly, the consequent displacement of the air causing the noise. If, however, the products of combustion are first expanded in a closed vessel, and then allowed to escape, their velocity and the atmospheric disturbance will be less and the noise produced will be of much smaller intensity.

2. The majority of I.C. engines are therefore furnished with some sort of silencer. Pl. **56**, Fig. 1, shows the type used for small oil engines. Its capacity should be from six to eight times that of the cylinder of the engine exhausting into it.

Silencers should be provided with a drain plug at the lowest point, to allow deposits of oil and condensed water to be drawn off. The pipe connecting the engine and silencer should not be of less diameter than that indicated by the flanges provided by the maker, or back-pressure during the exhaust stroke will result. All sharp bends should be avoided for the same reason.

A fairly long straight pipe between the engine and silencer is an advantage in four-stroke engines, as it tends towards the complete scavenging of the cylinder, owing to the momentum of the long column of departing exhaust gases. The silencers of two-stroke engines should be as near the engine as possible, to avoid back-pressure, owing to the comparatively short period during which the exhaust ports are opened.

Plate 56.

TYPICAL SILENCER, EXHAUST-PIT, BLOW-LAMP.

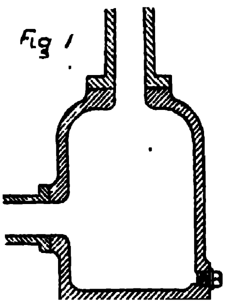


Fig 1

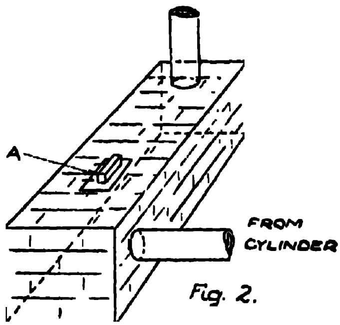


Fig. 2.

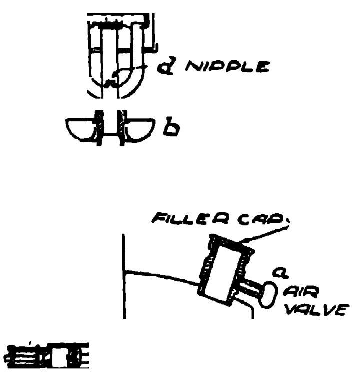


Fig. 3.

3. The silencer should deliver to atmosphere through a short pipe only, or else back pressure would be brought on the engine owing to its having to drive out all the expanded gases from the silencer through a long pipe.

4. Where extreme silence is required (*e.g.* near a military hospital), the silencer may, with advantage, be augmented with, or totally replaced by a large brick-lined silencing pit, as shown in Pl. **56**, Fig. 2.

A *safety flap*, A, should be provided to avoid any damage by an explosion in the pit, which will sometimes occur owing to a charge or charges from missed strokes finding their way into the pit and being fired by the hot exhaust gas of a subsequent explosion.

5. Where hot water or steam is required in small quantities, *exhaust heat boilers* can be obtained for utilizing the heat in exhaust gases for raising steam. Large savings can be effected by using this simple device. About 3 lb. of water can be evaporated per B.H.P. per hour.

CHAPTER XVI

GAS ENGINES AND PRODUCERS

76. *Principles of action of gas engines and producers*

1. The gas engine was the earliest form of I.C. engine and for a long time held a predominant position for small power units up to about 30 H.P., on account of its convenience when supplies of town gas were available. Now, however, that electricity is replacing gas, the scope of the small gas engine is limited.

The larger sizes of gas engine using producer gas form probably the cheapest source of power. The producer itself, however, requires very careful supervision to maintain it in efficient working order.

Diesel and semi-Diesel engines are generally more suitable for service purposes, but situations may arise where local supplies of wood refuse, coke, &c., exist in sufficient quantities to make the producer gas engine worth considering.

2. **Gas engines** are designed for working either with town supplies of gas or with gas locally made in the engine house.

Town gas has a higher calorific value than producer gas, and when mixed with air will explode spontaneously at lower temperatures. For town gas, compression pressures up to 120 lb. per square in. are usual, and for producer gas from 150 to 180 lb. per square in., depending on the chemical composition of the particular gas.

Pl. **49**, Fig. 1, shows a typical modern gas engine. The gas and air valves are combined in one valve, and governing is effected by varying its lift. Magneto ignition is employed.

3. **Gas producers** for the local manufacture of gas are designed to use anthracite, coke, charcoal and wood refuse, bituminous coal, or practically any solid hydro-carbon that will burn and is available in a large quantity.

Producer gas is made by passing steam and air, in correct proportions, over red-hot fuel. In most cases the air and steam are drawn through the fuel by the suction of the engine, the plant being then termed a *suction gas producer*.

In some systems, steam is generated in a separate pressure boiler, and is admitted to the fuel under pressure, through a nozzle and injector fitting, which induces a rush of air. The resulting gas is stored in a receiver and used as required. Such plants are called *pressure gas producers*.

The design of producers differs in details to suit the kind of fuel used.

Pl. **57**, Fig. 1, shows a modern suction gas producer plant designed for anthracite, coke, or charcoal. It consists of :—

i. A firebrick lined furnace, A, through the bottom of which air and steam enters.
ii. A steam-raiser, D, consisting of tubes into which water drips, and outside which the hot gas formed in the furnace circulates, thus converting it into steam.
iii. A scrubber, R, packed loosely with coke, through which water is kept trickling. The ascending gas is thoroughly washed thereby, all dust and impurities being extracted.
iv. A suction chamber and starting fan with blow-off pipe, which complete the equipment.

4. The principle of action is shown on Pl. **57**, Fig. 2. When the fresh fuel is added at the top of the furnace, it is heated by the hot gases passing upward through it, and the more volatile gases (*e.g.* ordinary coal gas) are given off, leaving the carbon behind.

As the hot carbon sinks lower in the furnace, it meets the highly heated steam and carbon dioxide which has been formed below. The steam is decomposed into hydrogen and oxygen, and the carbon dioxide picks up more carbon and forms carbon monoxide, $C + CO_2 = 2CO$. These reactions occur in the *decomposition zone.* Lower down in the furnace the remaining carbon is burnt to CO_2 by the incoming air, producing considerable heat which superheats the steam and assists in its decomposition.

The mixed gases that proceed to the scrubber are coal gases, carbon monoxide, hydrogen, and nitrogen, which, when mixed with air, will form an explosive mixture.

5. **Running a gas producer.**—The points to watch are :—

i. *Definite proportions of air and steam are essential ;* the mass of fuel must be kept hot enough to ensure the reactions outlined in para. 4, but not so hot as to clinker up (thereby preventing passage of air through it). The rate of producing gas is limited ; too much steam passed over the fuel tends to cool it, whereupon the decomposition action is not properly carried out ; too little results in excessive temperature in the furnace. Air must only be drawn in through the openings designed for that purpose, and, therefore, all joints must be good and able to prevent air leaks *into* the system.

The majority of faults and unsatisfactory production of gas are traceable to a contravention of these principles.

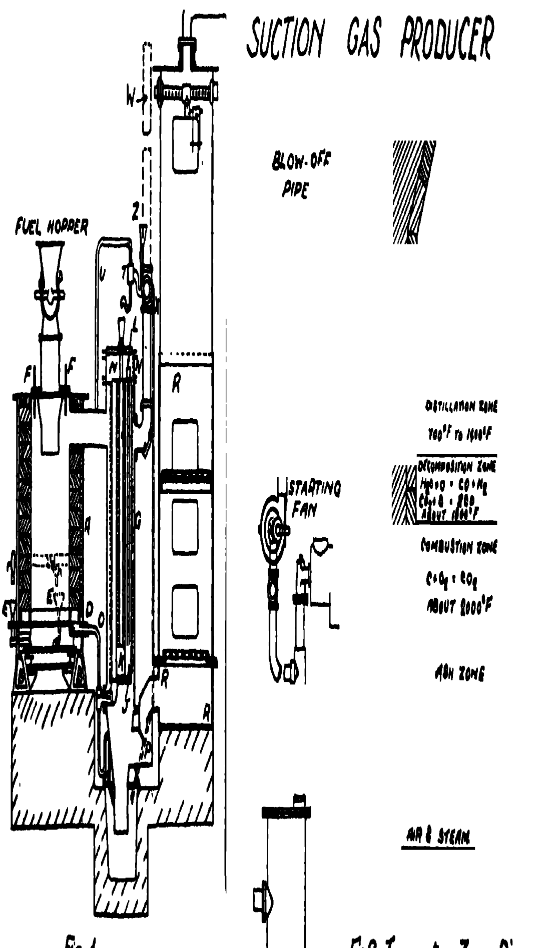


Fig. 1.

Fig. 2 Temperature Zone Diagram.

ii. The gas being poisonous, none must escape into the producer house or engine house. Water-seals are provided by the makers, and the fact that the engine, in sucking from the producer, produces pressure therein slightly lower than atmospheric, tends to prevent leakage outwards.

iii. Pure gas, free from tar and grit, must be supplied to the engine. Therefore, the *scrubber* must be kept in good order and frequently cleaned.

6. **Working gas producers.**—The following instructions are given as a guide, and refer to the plant shown on Pl. **57**.

i. *Anthracite.*—Anthracite should not be larger than 1-in. or smaller than $\frac{3}{8}$-in. cube. It should be free from dust, fairly uniform in size, and of a quality known as *machine-cut washed beans or peas.*

Care should be taken to protect it from the weather.

ii. *Coke.*—Gas-works or furnace coke. The coke should be broken to a size not larger than 1-in. cube and be free from dust and foreign matter. Gasworks coke varies greatly in quality and degree of carbonization. The quality recommended is described as *thoroughly carbonized and free from tar or volatile matter.*

A special tar-extractor is recommended to be added to the plant if the fuel cannot be obtained free from tar, otherwise trouble will be experienced with tar on the engine valves.

iii. *Charcoal.*—This fuel is very suitable for use with suction plants where it is impossible to obtain anthracite or coke. The main point to be observed with this fuel is that the wood is thoroughly carbonized, or trouble will be experienced with tar on the engine valves (*see* para. 3 *re* tar-extractor).

iv. When starting to work for the first time, after erection or long stoppage which necessitated the withdrawal of the fire, ash should be fed into the furnace to the height of the top plate of the stepped grate, leaving only a small space to light the fire. The fire should be started with wood chips and a small quantity of anthracite, coke, or charcoal, the chimney cock being partly closed to allow the fire to burn somewhat slowly for the purpose of drying the brickwork. This should be done, if possible, the night before it is intended to put the plant on load.

To prepare the plant for load, half fill the furnace with fuel and turn on the water to the scrubber, the step fire-grate, and the external vaporizer, G; after ensuring that the gilled tubes, J, K, &c., are full of water (this is denoted by the overflow through the siphon tube of the steam connection, O, to the seal box), regulate the water supply to the funnel, Z,

to a very slight dribble. The overflow, X, to the funnel, Z, and the cock, U, of the vacuum pipes should always be closed until the engine is running.

Open the blow-off pipe, and after oiling the hand-fan exhauster near the engine, turn it vigorously, blowing the waste gas into the atmosphere through the waste pipe from the exhauster. When the gas will light at the test cock on the outlet of the exhauster and continue burning, the blow-off pipe can be closed and the engine started.

It is most important that the engine be quite ready for starting at this point, as any time lost in starting the engine after the hand-fan exhauster has stopped would result in the cessation of gas-making, and the engine would probably pull up after running a few minutes.

v. *When the engine is running* on load, open the cock, U, on the vacuum pipe to the vacuum chamber, T, of the automatic water supply, and open the cock on the water overflow-pipe, X. The water supply to the funnel, Z, should be so regulated as to allow a constant overflow down the pipe, X, to the seal box, and the cock, U, should be so regulated as to allow an occasional drop of water to overflow from the siphon pipe of the steam pipe, O. The water supply to the stepped grates should be sufficient (at least) to prevent excessive temperatures being attained. The fuel adjacent to the grate should not be above dull red ; a small quantity only is necessary for this.

vi. *When shutting down the plant*, open the waste pipe, W, near the plant and immediately close the gas-cock on the engine, the water on the scrubber, and check the water supply to the step grate and external vaporizer.

To ensure a quick start when next restarted, it is an advantage to cease feeding the furnace for the last two or three hours of the previous run, and cleaning operations to the fire should be carried out immediately after stopping, so that the fire may be disturbed as little as possible when restarting.

Do not add any fuel to the furnace until the engine has started, and then gradually feed until the furnace is entirely filled.

vii. *During stand-by periods* at night or week-ends, the cock of the waste pipe, W, should be regulated to suit local circumstances ; to economize in fuel it is necessary to reduce the draught through the plant to a minimum, which may be accomplished by partially closing the waste-pipe cock.

A small quantity of water must be supplied to the external vaporizer, G, during stand-by periods.

The attendant should periodically poke the plant through the top poke-holes, F, according to the quality of fuel in use,

and all clinker should be removed from the side of the brickwork by this means. The ash and clinker can then be withdrawn from the step grate.

To avoid variations in the quality of the gas, it is advisable to leave the poke-hole open for as short a period as possible.

It is not necessary to clean out the fire more often than two or three times a day.

If a piece of clinker is too large to be drawn out, say, through the spaces above the top grate plate, it can be pushed by the poker to the centre of the fire; the centre of the fire itself is cleaned by drawing away a portion of the bed of ash upon which it rests in the middle of the generator.

viii. *Maintenance.*—If the water used is dirty or hard, the external vaporizer will require examining periodically and the tubes cleaning.

After about every 1,500 hours of work, the coke in the scrubber, R, should be renewed and the water sprinklers inspected to ascertain whether they are distributing the water freely.

Hard furnace coke should be used in the scrubber, and it should be broken to a suitable size, varying from 2- to 3-in. cube on the lower grid to, say, ¾-in. cube at the top of the scrubber.

Care should be taken that air is not sucked into the joints of the hopper; the rotary portion should be taken asunder frequently for the purpose of cleaning, and the springs and adjusting screws on the hopper body should be examined to see that they are properly adjusted to ensure an airtight joint.

7. **General.**—The precautions to be taken against gas poisoning are dealt with in Regulations for Engineer Services, Part II.

Producers using wood, bituminous coal, &c., make dirty gas (tarry), and special methods of purification are required.

Producers of all types require to be watched by a permanent man. They are, therefore, not suitable for use in the service.

The instructions given in para. 6 above are sufficient for working most of the small civil plants that are likely to be met with in war-time.

For Bibliography, see page 688.

CHAPTER XVII

PETROL ENGINES

77. *Introduction*

Petrol engines used by the R.E. may be of any power between 1 and 40 H.P.; may have one, two, four, or six cylinders, may be water- or air-cooled, and may be four-stroke or two-stroke.

Space will only permit of dealing mainly with the most usual types, viz. the one- and four-cylinder, four-stroke, water-cooled.

Information regarding the elementary principles of the action of four-stroke oil engines is given in Sec. **66**, and applies equally to petrol engines.

The main points of difference between petrol and oil engines are :—

i. The method of vaporizing the fuel and obtaining the explosive mixture.
ii. Ignition.
iii. Higher speed and, hence, much lighter construction for a given horse-power.
iv. Valve timing.
v. Governing.
vi. Compression pressure. The maximum compression pressure in ordinary petrol engines varies from 90 to 110 lbs. per square inch, as against 60 to 80 lbs. per square inch in paraffin engines.

78. *Principles of carburation and induction systems*

1. Petrol will evaporate completely at ordinary atmospheric temperature and pressure. Petrol and air will form an explosive mixture when in the proportion of from 1 of petrol to from 11 to 17 of air by weight. The true explosive mixture is about 1 to 15. This mixture gives the most rapid explosion, almost the greatest power, and reasonable economy of fuel. Richer mixtures of about 1 to 13 give rather more power, but lower fuel economy. Weaker mixtures of about 1 to 16 give slightly less power, but better fuel economy.

It is the function of a carburettor to form a homogeneous mixture of very fine liquid petrol particles and air in the desired proportion and to maintain the proportion as nearly constant as possible under all steady conditions of load and

speed. During starting, and under unsteady conditions such as sudden throttle opening or closing, acceleration or deceleration of the engine, the carburettor must provide a different proportion of fuel and air, for reasons which are explained later.

It is the function of the induction system to add heat to the mixture from the carburettor and deliver equal amounts of a partly vaporized mixture to the various cylinders of the engine in turn. Evaporation takes place partly in the carburettor, partly in the induction system, and partly in the inlet valve port. The remainder is effected within the hot cylinder itself. It is desirable that the mixture in the cylinder shall be not more completely evaporated at the end of the suction stroke than will ensure just complete vaporization at the moment of firing, otherwise the weight of explosive charge will be reduced. This is because liquid petrol occupies less room in the cylinder than gaseous petrol, and allows more room for air.

2. **Scent-spray principle.**—The fundamental principle on which nearly all carburettors work is well illustrated by the scent-spray, Pl. **58**, Fig. 1.

Air at high velocity is blown over the open end of a small tube or jet. The pressure at the top of the jet is thereby reduced below atmospheric, and liquid (under atmospheric pressure) rises in the tube until it reaches the top, where it is divided into an extremely fine spray and carried away by the rush of air. The greater the velocity of air past the jet, the more liquid will emerge, owing to the greater pressure drop. If the liquid is petrol, the fine spray will be in the right form for its complete vaporization.

3. **A simple jet carburettor for constant-speed engines** is shown on Pl. **58**, Fig. 2. This type is suitable for small stationary engines designed to run at a constant speed.

A needle valve, A, regulates the opening of a petrol jet, B, in which the level is kept constantly just below the outlet by means of a pump (not shown) and overflow pipe, C. The jet is situated in a narrow portion of the air passage through the carburettor, known as the *choke-tube*.

The object of a choke-tube is to increase the velocity of air past the jet so that a considerable pressure drop is produced at this point. This makes for good atomization, *i.e.* the breaking up of fuel into small particles. If the whole inlet passage were of a uniform section equal to that at the narrowest part of the choke-tube, air friction therein would cause a throttling effect on the mixture, thereby preventing the engine from drawing in a full charge. If made of the shape shown, air friction is relatively small. By regulating the needle

PLATE 58.

CARBURETTORS.

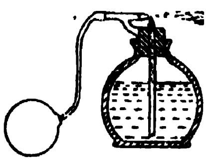
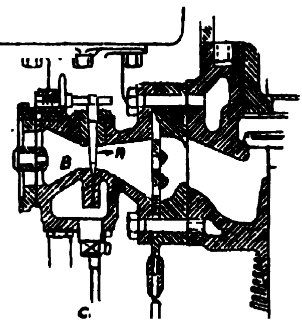
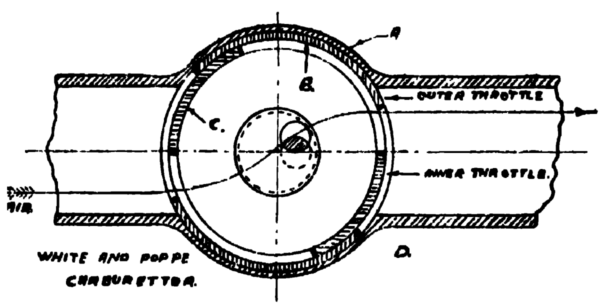


Fig 1 SCENT SPRAY



ARBURETTOR

LISTER PETROL ENGINE.
Fig 2



WHITE AND POPPE
CARBURETTOR.

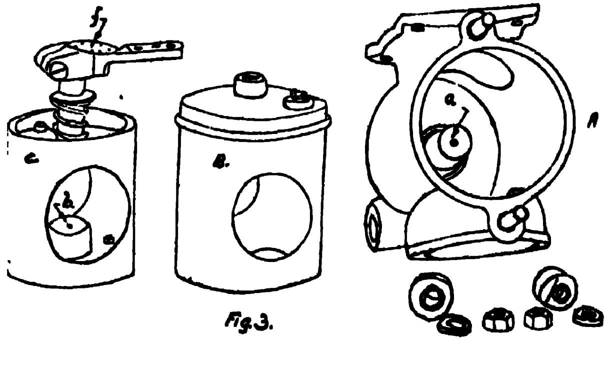


Fig.3.

valve, A, sufficient petrol can be mixed with the incoming air to form an explosive mixture.

4. In an arrangement such as that just described, if the air speed past the jet is increased for any reason, the amount of petrol drawn out of the jet increases at a rate greater than that of the increase in air speed. This results in a mixture richer in petrol. If the air speed is decreased, the proportion of petrol decreases and the mixture is weaker. Variations of air speed do occur, even at constant engine speed, in this carburettor according to the position of the throttle. The throttle in Pl. 58, Fig. 2, is a perforated slide operated by the governing gear. Under full load the throttle will be fully open, and air speed a maximum, but under lighter load the throttle will be more or less closed, and the air speed lower owing to the restriction of the bore. As, however, mixtures of petrol and air are explosive between the proportions of 1 to 11 and 1 to 17, the engine will continue to function sufficiently well at all throttle openings, provided that the engine speed does not change.

If it were desired, however, to change the speed, from, say, 400 to 600 r.p.m., as the mean air speed past the jet would increase by 50 per cent., too much petrol would be drawn out in proportion to the air to form an explosive mixture in the engine cylinder, and it would be necessary to readjust the needle valve to give a smaller opening of the jet.

5. **Starting.**—At starting, the engine can only be turned slowly, and, therefore, the air velocity past the jet is small. This results in too weak a mixture, which is not well atomized; therefore the starting of a cold engine which has not a sufficiently warm cylinder to vaporize the relatively large drops of petrol in the mixture is made very difficult. If, however, the needle valve is farther opened, enough petrol can be drawn out of the jet by the velocity of air to form an explosive mixture.

6. With this type of carburettor two marks are generally made on the needle valve, one for starting (*i.e.* fairly open) and the other for running (nearly closed). An adjustable air slide, D, is also provided. If this is closed at starting, a direct suction is induced over the jet when the engine is turned. In cold weather the jet will need to be opened a little more fully than in warm weather to compensate for the greater density of the cold air, and for the fact that less petrol will be evaporated by the colder air at starting.

7. **Carburettors for variable-speed engines** (automatic carburettors).—The majority of carburettors fitted to petrol engines used in the service will be of one of the standard types fitted to motor-cars. Here the problem of

constantly-varying engine speeds has to be dealt with. It is not practicable for the driver of a motor vehicle to be constantly adjusting a device such as a needle valve or extra air inlet. Such carburettors, therefore, are designed with the object of obtaining automatically a uniform mixture at all conditions of load and speed, the driver having only to open or close a throttle valve.

8. **Float chamber.**—All carburettors of this type have one point in common, viz. the float chamber, the object of which is to maintain petrol at constant level for feeding to the jet.

Petrol is fed to the bottom of the float chamber, Pl. **60**, Fig. 1, through a hole, in which fits a needle valve.

The hollow metal float is free to move up and down in the chamber. As the petrol enters the float rises, and eventually, through the small levers shown, presses the needle valve down, and shuts off the supply.

Floats are normally arranged to shut off the supply when the petrol level is $\frac{1}{16}$ in. below the top of the jet, in order to prevent any chance of leakage at the jet when the engine is not running.

It may be necessary to alter this adjustment on any alteration of the specific gravity of the fuel, owing to change of temperature or change of fuel. This can be done either by altering the distance between the collar and the point of the needle or by weighting the float. Many modern float chambers are fed from the top, and the needle valve is then lifted directly by the float on to the valve seating, thus cutting off further petrol supply. This is a simpler arrangement and avoids the pin wear which takes place when levers are used.

9. The troubles with float chambers are :—

i. Water and dirt accumulation from unfiltered petrol.
ii. Faulty needle valve point or seating due to wear causes permanent flooding and waste of fuel. This can be remedied by grinding in by hand with fine emery and oil. If a bad shoulder has been formed on the needle, it is better to grind it on a machine and afterwards fit to the seating by hand.
iii. Bent needle, caused by rough handling. Causes flooding. Test for straightness by rolling on a flat table.
iv. Punctured float. This sometimes happens owing to faulty soldering, resulting in petrol getting inside, increasing the weight, and so causing flooding. The petrol can be got out by warming (with due care). The petrol evaporates away, after which the puncture can be mended by very careful soldering.

10. **Mixture adjustment or compensation at varying speeds.**—There are several methods of obtaining a constant mixture in carburettors for variable-speed engines.

i. The most common is the *constant velocity* or *varying choke and jet* method. The principle can be understood by reading Sec. **79**, para. 1, on the *White and Poppe* carburettor. The principle applies to the *B. & B.* and *Amal* carburettors. The *S.U.* (Pl. **59**, Figs. 2 and 3) and *Smith multiple jet* (Pl. **59**, Fig. 1) also work on this principle, though in these cases the variation of the choke-tube and jet is not mechanically effected by opening the throttle, but by means of a suction operated piston. The amount of suction on the piston in these cases is controlled by the amount of throttle opening in conjunction with the engine speed. This imparts a certain delay action on the variation of choke and jet (or jets) because of the elasticity of the suction and the inertia and friction of the piston. The desirability of this feature is explained in para. 12.

ii. *The compensating jet method.*—This is typified by the *Zenith* carburettor, explained in Sec. **79**, para. 4.

iii. *The submerged jet method.* (*See* Sec. **79**, para. 5.)—The *Solex*. In this type a very rich mixture of petrol and air is drawn into a fixed choke-tube through a comparatively large orifice. The jet proper (through which petrol *only* flows), which is submerged below the petrol level of the carburettor, is not, therefore, under such direct influence of the air stream in the main choke-tube, and there is, therefore, less need for adjustment of mixture strength with varying air speeds. This may be understood better by considering the fact that the orifice protruding into the air stream of the choke-tube is delivering a mixture of petrol and air, and, therefore, a more constant proportion is naturally maintained than is the case with petrol only.

iv. *Automatic air-valve principle.*—In this, which is typified by many American carburettors, the jet is usually of normal non-submerged type and the choke fixed. Extra air to compensate for the enriching of the mixture at higher speeds is introduced by an automatic air-valve, which is opened by the suction of the engine. A light spring keeps it on its seating at low speed. This method often results in over-compensation, and the jet is often provided with a tapered needle, which is lifted out by a mechanism connected to the throttle, thus enlarging the jet orifice.

11. **Starting and slow running.**—All carburettors must give to the induction pipe an over-rich mixture for starting from cold, owing to the lack of vaporization at low temperature. By the time such mixture has filled the cylinder and has

been compressed, enough of the petrol in it will have evaporated to make a mixture of gases that will be explosive.

A strangling device is usually provided, whereby the air supply to the main choke-tube can be cut off. This causes a considerable suction effect around the jet, which then delivers enough petrol for starting, even at hand cranking engine speeds. The hand or a rag make a good substitute for a strangler, when none is fitted.

Nearly all car type carburettors also have a special device for assisting starting and making for economical slow running or idling, as when waiting in traffic blocks. This consists of a miniature jet (the pilot jet) and miniature choke-tube, which come into operation only when the throttle is almost closed. It is nothing more than a tiny carburettor, and it suffices to refer to the slow running device on the *Zenith*. (Pl. **60** and Sec. **79**, para. 4 (ii).)

12. **Acceleration.**—When the throttle is opened with the engine running, the pressure (below atmospheric) in the induction pipe increases more or less suddenly, according to the suddenness of the throttle opening. This is because the engine cannot accelerate quickly enough, and the air from the outside has time to fill up the vacuum or depression in the induction system. This increase of pressure, if at all sudden, causes a considerable precipitation or deposition in the piping of petrol which may have already been vaporized. The result is a weak mixture delivered temporarily to the cylinder.

Most modern carburettors have an arrangement by which an over-rich mixture is supplied when the throttle is opened, the excess petrol only lasting for a few cycles. The delay action of the suction operated piston in the *S.U.* and *Smith multiple-jet* carburettors (*see* para. 10, i.) produces this effect (as well as the reverse on throttle closing).

The inertia of the petrol as compared with the air is a further cause of the reduction in strength of mixture during acceleration.

13. **The requisites of a good automatic carburettor** may be summarized as follows :—

i. Must always make a well atomized and homogeneous mixture.
ii. Must provide a nearly constant proportion of air to fuel at all speeds and loads, except when starting.
iii. Must provide an excess of petrol for starting and also, but to a lesser extent, for acceleration.
iv. Must be simple to adjust and must remain in adjustment in spite of wear.
v. Must contain the minimum of small moving parts.

Sec. 79 gives typical examples of carburettors in most common use in the service and show how these points are catered for.

79. *Types of Carburettor*

1. The White and Poppe carburettor.—(1) The White and Poppe carburettor, as fitted to P.E. lorries, &c., acts on the *constant velocity principle.*

The carburettor body, Pl. 58, Fig. 3, consists of a cylindrical chamber, A, containing the jet, *a*. The cylindrical adjustable liner, B, fits closely in the body, and the cylindrical, throttle valve, C, rotates in the liner, B. Fixed to the throttle cylinder is a cap, *b*, which fits over the jet, *a*. Both cap and jet are drilled eccentrically, so that as the throttle is rotated the actual jet opening is varied.

As the throttle is opened, the increased passage given to the air tends to keep the velocity past the jet constant. Constant air velocity passing a jet of a given size gives a constant quantity of petrol. As the throttle is opened, more air passes, and the size of the jet opening is increased proportionately, so that a constant mixture is obtained.

(2) The function of the liner, B, is one of adjustment. To vary the strength of the mixture, the liner is turned relative to the carburettor body. For any one position of the throttle lever the same area of jet will be uncovered ; but by turning the liner, the actual amount of *throttle opening* (*i.e.* passage to air) for any position of the throttle, can be varied, thus causing a mixture of varying strength.

(3) A fine adjustment for altering the strength of the mixture to suit the weather is given by the snail cam, *f*. This allows more or less air to leak over the jet through the throttle spindle, which is drilled.

Once the main adjustment is set for any engine, this should be sufficient for any temporary adjustments.

(4) This is a good carburettor for service purposes. It gives a fair economy, is foolproof, and the jet can be made so large that grit, the enemy of carburettor jets, will not readily lodge in it. It gives poor acceleration, because no provision for an over-rich mixture is made (*see* Sec. 78, para. 12). It has no slow-running jet.

2. The Smith multiple jet carburettor.—*See* Pl. 59, Fig. 1. This carburettor works on the same general principle as enunciated in Sec. 78, para. 10 (i), the variation of choke area being effected by suction. It will be seen that as the suction on the carburettor side of the throttle increases, the piston, P, which is quite heavy, will uncover successively the holes in the choke-tubes, 1, 2, and 3, thus

PLATE 59.

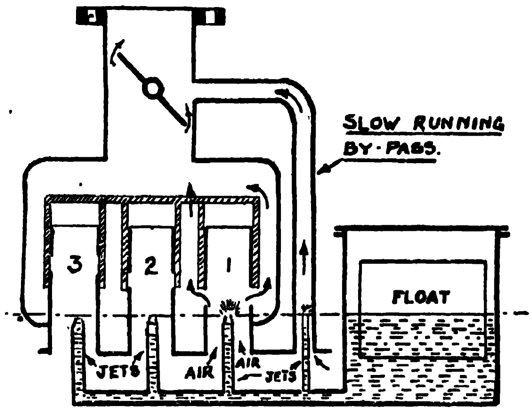


Fig 1. Multiple Jet Carburettor.

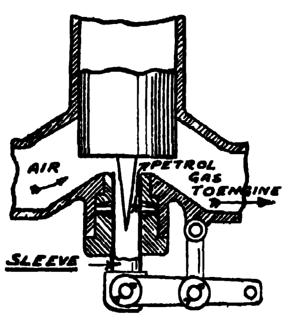


Fig. 2.

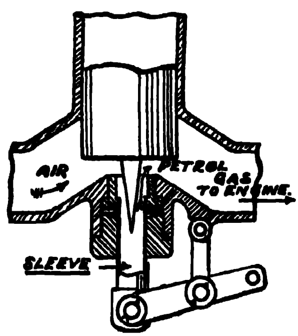
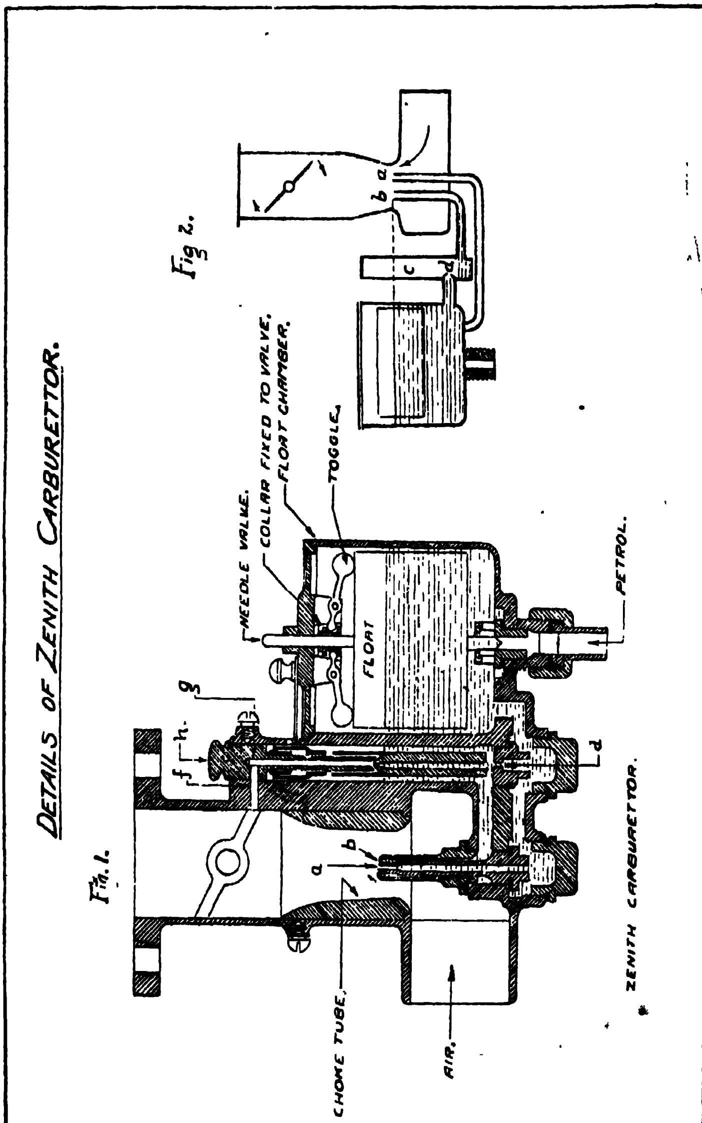


Fig 3.

S.U. Carburettor.

Plate 60.


DETAILS OF ZENITH CARBURETTOR.
Fig. 1.
Fig. 2.
NEEDLE VALVE.
COLLAR FIXED TO VALVE.
FLOAT CHAMBER.
TOGGLE.
FLOAT
PETROL.
ZENITH CARBURETTOR.
CHOKE TUBE.
AIR.

bringing the jets into operation one by one. This really amounts to having several carburettors combined in one, each adding its share of the mixture as the engine demands.

Multi-jet carburettors are usually thought too complicated for service purposes. Their only drawback is that there are several small jets to get choked with dirt in place of one large one.

3. **The S.U. carburettor.** *See* Pl. **59**, Figs. 2 and 3. *See* Sec. **78**, para. 10 (i), for the principle of its mixture strength compensation. This carburettor has no special slow-running device. Starting from cold is effected by lowering the sleeve which surrounds the jet needle. This makes the jet larger and gives as rich a mixture as necessary. This operation can be performed from the dashboard. It is a very simple matter to tune this apparatus, it only being necessary to adjust the upper limit position of this sleeve. The higher the sleeve the weaker the mixture at all throttle positions. The jet needles must sit centrally in the sleeve, and care is required when the piston is removed not to damage the needle. The dashboard control of the jet is very useful when running under different atmospheric conditions.

4. **The Zenith carburettor.**—(i) *The Zenith carburettor* illustrates the principle of the *compensating jet.* On Pl. **60**, Figs. 1 and 2, the float chamber communicates with the main jet, *a*, direct, and with a compensating jet, *b*, via the vessel, *c*, the top of which is open to the air. Petrol will flow into *c*, through the small orifice *d*, at a rate dependent on the difference of level of petrol in the float chamber and the vessel, *c*. The flow through *d* is unaffected by the drop of pressure at the jet, *b*, owing to the vessel, *c*, having an open top.

For running at normal rates of speed the petrol is delivered through the jet, *b*, as fast as it will flow from the orifice, *d*, so that the chamber, *c*, is then empty; petrol thus flows into *c* at a constant speed.

Both jets are situated in a choke-tube and the proportion of petrol issuing from the main jet, *a*, to air increases as the air speed past the jet rises. The jet, *b*, will not deliver more petrol per second than can flow in through *d*, and, therefore, as the air speed past the jets increases the proportion of petrol to air delivered by jet, *b*, decreases. Hence, on an increase of air speed, the action of jet, *a*, is to make the mixture stronger and that of jet, *b*, to make it weaker.

By suitably proportioning jet, *a*, orifice, *d*, and the choke-tube, a carburettor can be produced which will give a fairly correct mixture at all speeds and loads.

Pl. **60**, Fig. 1, shows the actual construction of the Zenith

carburettor. It will be seen that the compensating jet surrounds the main jet. It is more usual to call the orifice, *d*, the compensating jet, and the annular jet, *b*, is then referred to as the compensating jet tube.

(ii) *Starting and slow running.*—The chamber, *c*, contains a small subsidiary carburettor for easy starting and slow running. It delivers into the induction pipe above the choke-tube, through the passage, *f*.

When the engine is not running, chamber *c* fills up to float chamber level. With a practically closed throttle the engine is cranked, and a comparatively high air velocity is obtained through the narrow opening, *f*, resulting in the sucking in of petrol through the passage, *g*, and a rich mixture for starting. If the throttle valve were opened too wide, difficulty would be experienced in starting, as the air velocity would not then be large enough to form a rich mixture either from the main or compensating jets or from the pilot jet, *f*.

(iii) Immediately the engine starts, the level of the petrol in *c* will be lowered. When the engine is running slowly under no load, the petrol will rise a little way in *c*. When the throttle is opened the jet, *b*, can first of all draw on the reserve of petrol in *c*, thus providing a temporarily over-rich mixture. The level in *c* is thus gradually lowered. Immediately normal loads and speeds are reached, petrol is drawn out of *c* by the jet, *b*, as fast as it can run into *c* through *d*.

(iv) This carburettor has the following advantages :—

i. Good compensation.
ii. The slow-running device is easily adjusted, and as it gradually goes out of action when the throttle is opened, waste is avoided.
iii. A good reserve of petrol for acceleration. If the throttle is opened too suddenly, however, the reserve is drawn off too quickly. This may result in too rich a mixture to fire, and the engine stops. This is called choking (lack of air).

(v) *Adjustments.*—The main adjustments of Zenith carburettors will usually be made by the engine maker to suit the particular engine. They are :—

i. By changing the diameter of the choke-tube.
ii. By changing the main jet.
iii. By changing the compensator, *d*, which regulates the rate of flow of petrol through the compensating jet.

It must be remembered in changing Zenith jets that the main jet has most influence on the mixture at high speeds and full throttle, and that to test the effect of the main jet, the

PLATE 61.

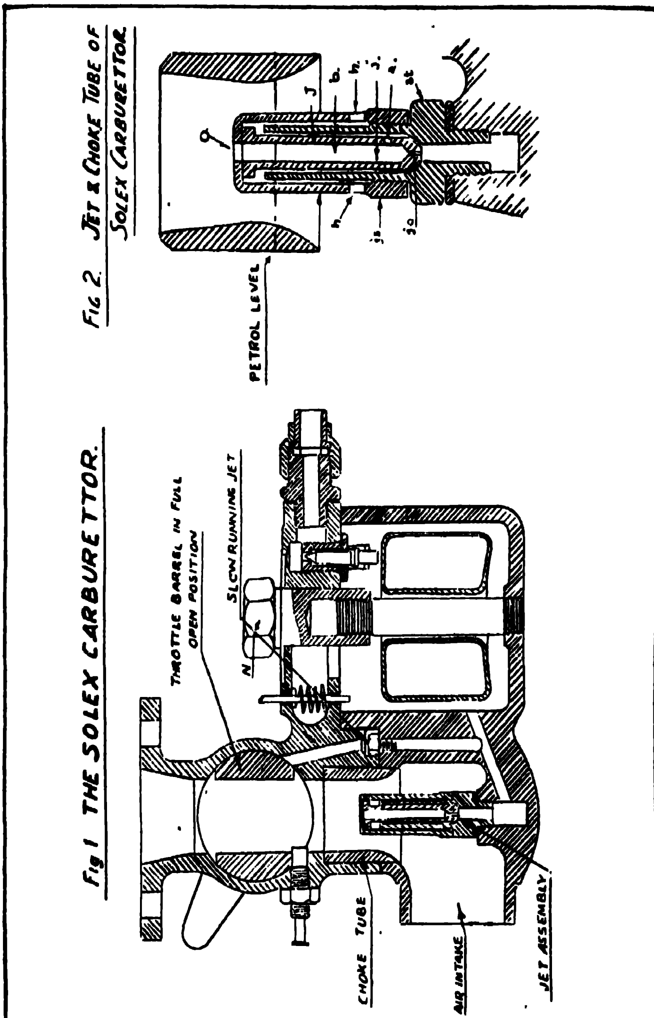


Fig 1 THE SOLEX CARBURETTOR.
THROTTLE BARREL IN FULL OPEN POSITION
SLOW RUNNING JET
N
CHOKE TUBE
AIR INTAKE
JET ASSEMBLY
Fig 2 JET & CHOKE TUBE OF SOLEX CARBURETTOR
PETROL LEVEL

engine must be at full speed and throttle. The compensator has most effect at low speeds and loads, and, therefore, experiments with it should be made at intermediate loads and throttle openings.

The minor adjustment provided is merely for slow running, and consists of reducing the size of the choke-tube in the slow-running auxiliary carburettor. The normal adjustment is given by screwing down the mill-headed piece as far as it will go, and then turning 1½ turns back.

5. **The Solex carburettor.**—Reference should be made to Pl. **61**, Figs. 1 and 2, and to Sec. **78**, para. 10 (iii). The carburettor throttle is of barrel type, which concentrates the suction on to the pilot jet for starting and slow running, but cuts that jet out at large throttle openings. The petrol normally stands at the level, shown in Pl. **61**, Fig. 2, when the engine is stationary or running light. As soon as the throttle is opened, the reserve of neat petrol in and around the body, *b*, of the main jet, *j*, is drawn through the large opening, O, giving the necessary over-rich mixture. The level is gradually lowered until holes, *a*, are uncovered, when air can enter via holes, *h*, in the jet shroud, *js*, round the top of the jet standard, *st*, and in through the holes, *a*, in the jet, *j*. A mixture of petrol and air is then delivered from O.

The maximum amount of petrol which can flow is limited by the jet orifice, *js*. This principle of leading a mixture into the main choke via O, results in excellent atomization, which has a marked effect on petrol consumption.

This carburettor has the important advantage that the float chamber and jet assembly can be removed without breaking a single petrol connection, by merely unscrewing nut, N.

Adjustment comprises choice of choke-tube, main jet and slow-running jet. It is a disadvantage not having an adjustable slow-running jet.

80. *The fitting and tuning of carburettors*

1. Sizes of flanges which abut anywhere in the induction system should be the same, so as to avoid sudden enlargements or contractions in the bore. This governs the size of carburettor to fit. The common sizes of carburettor are 26, 30, 35, 40, 46, and 52 mm., this measurement being the internal diameter of the mixture outlet from the apparatus.

When fitting a carburettor, make sure there are no air leaks where it joins the induction pipe, or in the induction pipe itself. Any thin jointing material is suitable. See that the float chamber is vertical and that the petrol level is just

below the level of the top of the jet. Note that petrol will rise higher up fine jets than large ones, owing to capillary attraction. Do not attempt to tune with flooding carburettor.

2. Before any carburettor adjustment is made, make sure that the engine is otherwise in good working order, especially as regards the valve timing and tappet clearances.

As a general rule, the first step in tuning is to get the slow-running system working, so that the engine can be started and warmed up. Adjustments to choke-tube and jet should always be made with a warm engine, and with as constant atmospheric conditions as possible.

3. The next step is to fit a choke-tube and jets of the right size, and it must be realised before commencing that the choice of size of choke depends on the results required. If the maximum power at high engine speeds is required (*i.e.* maximum speed on the level), the choke should not give any restriction of bore at all. This adjustment will give poor results at lower speeds, both as regards power and economy, because of the comparatively poor atomization. Economy and good acceleration at medium loads, at the expense of maximum speeds, is obtained by reducing the choke area. This can be carried out step by step until the maximum speed comes down to the lowest allowable limit. Makers' instruction books, when available, should be consulted as a rough guide to start with; they usually provide for good economy and acceleration rather than high power. These instruction books also serve the very useful purpose of indicating the choke and jet sizes which approximately correspond. The method of choosing the jet size for use with a given choke is by trial and error, guided by makers' instruction books.

The above remarks do not, of course, apply to automatically variable choke carburettors such as the S.U. In these the problem is much simpler and comprises adjustment of jet size only.

Do not reamer or hammer jets to alter their size unless absolutely necessary to do so.

4. The following symptoms of rich and weak mixtures are given to assist in tuning :—

(*a*) **Running light on slow-running device (cold engine).**

i. Engine runs regularly for a few moments only, then stops—insufficient *quantity* of mixture.

ii. Engine runs irregularly and may or may not stop—*weak* mixture.

iii. Engine hunts. In a four-cylinder engine, usually four strong explosions regularly followed by four weak ones, as heard at the exhaust—mixture *just too rich.*

iv. Engine misses every other explosion regularly—mixture much too *rich.*

(*b*) **With the engine under load and warm.**

i. Occasional popping in the carburettor and induction system—*weak* mixture.

ii. Irregular misfiring and frequent popping—*very weak* mixture.

iii. Black smoke issuing from exhaust—*rich* mixture.

iv. Black smoke issuing from exhaust accompanied by regular misfiring (eight stroking)—*very rich* mixture.

There is a considerable range of mixture strengths around the correct one, which will give none of the symptoms mentioned. The best strength of mixture within this range can then only be detected by power and economy tests.

5. In many cases where the induction system does not provide sufficient heat for partial vaporization (by conduction from hot spots of the engine), it may prove beneficial to heat the air before it enters the carburettor. Pl. **62**, Fig. 1, shows a method of doing this. The air passes through a muff, A, on the hot exhaust pipe, before entering the carburettor. Another method is to surround the induction pipe or carburettor body with a hot water jacket. Heating of this nature leads to economy of fuel provided it is not overdone.

81. *Petrol supply to carburettors*

1. There are various systems :—

i. **Gravity.**—The petrol flows by gravity from a tank which is so placed that the level of fuel is always higher than the top of the float chamber.

ii. **Vacuum system.**—The *Autovac* system is typical, Pl. **62**, Fig. 2.

The operation can best be understood by reference to the diagram, in which it will be seen that engine suction is used to draw up petrol from a main tank situated lower than the carburettor. The fuel is lifted to a small expense tank which is within the autovac itself. Thence petrol flows by gravity to the carburettor. The action is entirely automatic.

An autovac must be installed so that the top of the container is always above the level of petrol in the main tank, and the bottom must always be at least 3 inches above the level of petrol in the carburettor float chamber.

PLATE 62.

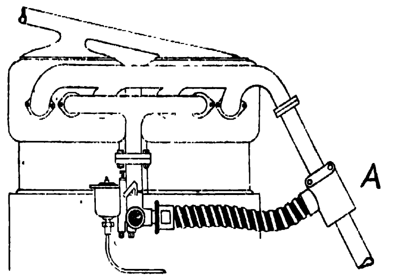


Fig 1

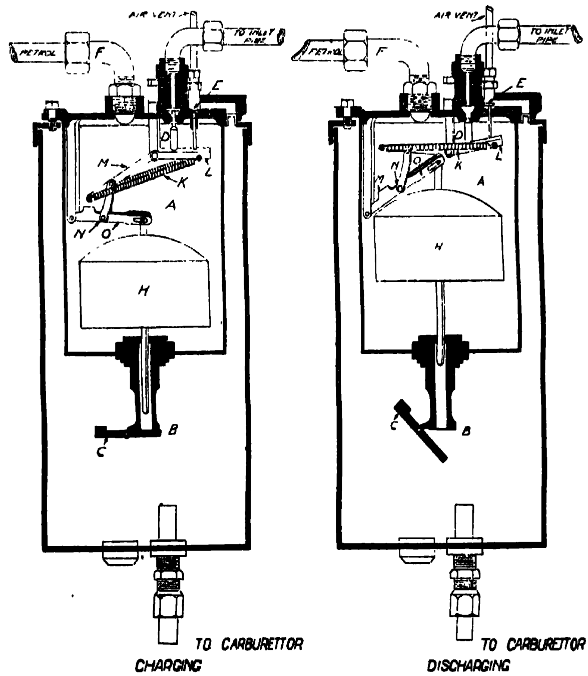


Fig. 2 The Autovac.

The pipes and connections must always be perfectly airtight. Provision is made to filter the petrol where it enters the container. This filter needs occasional cleaning. Any water or foreign matter which finds its way into the container can be drained off from the bottom via a cock provided. Otherwise the instrument needs no attention and should not be tampered with by unskilled hands. The valves are quite reliable.

iii. **Air pressure system.**—This is now rare. The main tank, which has to be airtight and strong, can be lower than the carburettor. Air at a few pounds per square inch (say, 3 lbs.) is supplied by a small air pump, operated by the engine, to the air space above the fuel in the main tank. This is sufficient to force petrol up the supply pipe to the carburettor. An auxiliary hand air pump is provided for starting purposes. A pressure gauge connected to the petrol tank is fitted for the convenience of the driver.

iv. **Pump system.**—Petrol pumps, either engine driven or electrically driven, are now being largely used in modern vehicles to raise the fuel up to a small expense tank above the carburettor level.

2. Petrol pipes should be of copper, softened by quenching in cold water from a red heat. They can then stand considerable vibration. They must be free from sharp bends likely to lead to fracture, and free from unnecessary upward slopes, which in gravity feed pipes sometimes cause mysterious air-locks.

Petrol tanks for gravity and vacuum supply must have an air vent. It is usually in the filter cap and must be kept free, otherwise petrol cannot flow out of the tank when the cap is on.

The lay-out of the supply system must avoid the possibility of leakage petrol dripping on to hot exhaust pipes.

3. **Filtering.**—All supply petrol contains impurities, of which water and a sandy substance are the commonest. If these get into the carburettor trouble ensues. Filters should always be fitted to the petrol system. The filters themselves need occasional cleaning, but this can be done when convenient. It must not be forgotten. The most common type has fine wire gauze for catching solid matter and a gravity trap which catches the water.

82. *Ignition in petrol engines*

1. In all petrol engines ignition is effected by an electric spark. This spark occurs within the cylinder when the piston is approaching the inner end of its travel on the compression stroke. The exact moment at which the spark occurs is dealt with in para. 4.

The spark is produced by one of two main ignition systems, viz. :—

i. Magneto.
ii. Battery and coil.

These systems are dealt with in Secs. 83 to 85.

2. **Sparking plugs.**—Pl. 69, Figs. 1 and 2. These vital components of a petrol engine receive a high voltage momentarily from the ignition system, with the result that a spark occurs at the sparking plug points protruding into the combustion chamber. The electric current passes down the insulated central electrode and jumps across the small air gap provided to a plug point, whence it returns to the ignition apparatus via the metal of the engine.

The following are practical points in connexion with sparking plugs :—

i. The proper length of air gap or spark gap for general purposes is 1/40 in. or ·025 in. The effect of a longer gap is to make starting more difficult and to put an extra and unnecessary electric strain on the sparking plug insulation and the ignition system. This applies equally to two-stroke engines. A shorter gap may give easier starting, but may involve a slight loss of power. If a shorter gap is necessary to get the engine to start, the plug insulation may be weak (breaking down when the gap is correct); otherwise the ignition system is at fault.

Spark gaps should be adjusted with the aid of a gauge of the correct thickness. Light tapping of the points will bend them quite well. Do not bend the central electrode unless it is the only possible way of adjusting the gap. If this electrode is not perfectly straight as is nearly always the case, gap adjustment may be made by revolving the electrode. This cannot be done in types of plugs which cannot be dismantled for cleaning.

ii. **Cleaning plugs.**—An over-rich mixture or a very late ignition may result in a thin layer of fine carbon being deposited on those surfaces of the plug which are within the combustion chamber. If any such layer gets across the surface of the insulation, the current will be short-circuited, and either no spark will occur or the spark will be weakened. Deposits of slightly or entirely carbonized oil have a similar effect. The immediate remedy is to clean the plug. This should be done by dismantling it, if possible, and scraping all the metal surfaces clean of carbon. The insulating surfaces need more careful treatment, and a wipe over with a rag is often sufficient. Before re-assembling, wash the parts clean in petrol. A less efficacious but quicker method is to wash the

plug in clean petrol without dismantling, and this is about all that can be done to plugs which do not take to pieces. The practice of cleaning plugs by heating in a blow-lamp or similar flame is bad as the heat required to burn off the carbon will damage the insulation. A very gentle heat, however, may be used to dry out the insulation and so improve its electric resistance.

A more permanent remedy for sooty or oily plugs will also be desirable. Cures for soot due to rich mixture or late ignition are obvious. Cures for oiliness are not so easy. The trouble is either due to :—

(*a*) Excess lubricating oil in the combustion chamber, or

(*b*) The use of the wrong type of sparking plug.

(*a*) is commonly caused by excess or unsuitable lubricant in the crank chamber, or by worn pistons, cylinders, or rings. In some engines, especially those with overhead valves, it may be due to worn inlet valve stems or valve guides, which allow oil to be sucked through. Faulty engine design is also quite often the cause of (*a*).

As regards the type of plug, all plugs are to a certain degree self-cleansing. They get hot enough to burn away some oil and carbon which is deposited on them. If the plug keeps too cool, the rate of cleansing is less than the rate of deposit, and the plug oils up. If it is too hot, it is kept quite clean, but then the electrode and points may get red hot and cause pre-ignition. The rate of cooling of the plug depends to a large extent on the size of the central electrode and points and the material used in them. Thin wiry points conduct the heat away slower than thick ones. High compression engines, in which the average temperatures are high, therefore require plugs with heavy electrodes ; low compression engines with lower temperatures require much thinner electrodes.

But electrodes are by no means the only factor in plug design for high or low compression engines. If plugs designed for low compression are used in high compression engines, the result is pre-ignition (at any rate at full throttle). If plugs designed for high compression are used in low compression engines, the result is oiling up (at any rate at small throttle openings). Therefore, where possible, maker's advice should be sought as to the most suitable type of plug.

Owing to the more frequent explosions, two-stroke engines require plugs which will stand higher temperatures than occur in four-stroke engines of equal compression, unless they are run only at light load. Plugs with a small vacant space within their bodies are less prone to cause pre-ignition than those with a larger space, other things being the same,

but the smaller space is sooner choked with carbon and is more difficult to clean.

3. **Testing plugs.**—The commonest method is to unscrew the plug from the cylinder and lay it with the body making metallic contact with the engine, the terminal being connected up to the ignition system. The spark points must be in view, preferably in a darkish place. If the engine be now rotated by hand, as for starting, a fat bluish spark should be seen. If there is no spark, or only a feeble, thin, or reddish one, disconnect the electric lead from the plug and make it spark to the metal of the engine. This will tell whether the fault lies in the plug or in the ignition system. If a plug gives a feeble, thin, or reddish spark when outside the cylinder, it may be giving no spark at all when inside the cylinder. This is because the voltage necessary to jump the air gap is greater under the cylinder compression than when in the atmosphere. When in the cylinder, the extra voltage required may break down a faulty or dirty plug insulation, resulting in no spark at the points. This is most important and makes plug testing more or less a matter of experience, when no special apparatus is available. There are cheap neon tube plug testers on the market which will indicate a satisfactory or otherwise spark with the plug under compression, *i.e.* in place in the cylinder.

4. **Spark advance.**—Owing to the appreciable time taken by the explosion to develop after the spark has taken place, it is necessary, if maximum combustion pressure is to be reached by inner dead centre, for the spark to occur some time before the piston reaches the end of the compression stroke. This is termed spark advance and the amount is usually spoken of in terms of crankshaft degrees before inner dead centre. The amount of advance is normally adjustable by the driver, the range being usually from nothing (*i.e.* spark occurs when piston is at inner dead centre at end of compression stroke) to, say, 30 degrees before inner dead centre. Rapidly burning mixtures, such as those of correct chemical proportions, hot, well vaporized, in a turbulent condition, and highly compressed, will require less spark advance at a given engine speed than mixtures which, owing to weakness or richness, lumpiness, stagnation or lower pressure, are more sluggish in burning.

The higher the speed, the earlier should the spark occur, up to a limit, owing to the shorter time available. The limit is probably where the extra turbulence due to speed more than counterbalances the shorter time available at the higher r.p.m.

From the driver's point of view the only variables are

speed and throttle opening (which governs compression pressure and temperature), and for his benefit the following hints are given :—

i. Full speed and light load (small throttle opening)—maximum spark advance (for compression pressure is then low, engine is cool, and very short time is available for combustion).
ii. Full speed and load (throttle wide)—nearly maximum spark advance (unless engine dirty and overheating, when further retard will be necessary).
iii. Slow speed, light load—half retard.
iv. Slow speed and heavy load (throttle wide)—full retard.

The symptoms of too much *advance* are :—

i. A dull thumping sound, caused by too early a rise of combustion pressure whilst the piston is still on its in-stroke.
ii. A sharp metallic *pinking*, which is due to partial detonation taking place after the explosion has been started by the electric spark, when the rises of pressure and temperature in the cylinder have together reached that point at which the yet unburnt portion of the charge ignites spontaneously. This will be accompanied by overheating, and the general intensity of these symptoms will depend largely upon the degree of cleanliness of the inside of the cylinder. Such pre-ignition must always be checked at once by retarding the spark or reducing the throttle opening, or by both, as it causes undue stress on the bearings, &c., which will result in wear.
iii. Unusual back-firing when starting.

The symptoms of too little advance are :—

i. The engine fails to develop full power and gives poor acceleration (without popping back) on throttle being opened.
ii. The engine overheats badly (exhaust system may become red hot) and flames may sometimes be seen at exit from exhaust box.
iii. Fuel consumption is abnormally high.
iv. Unusually loud and " flat " exhaust note.
v. Bad pitting of exhaust valves.

5. The position of the sparking plug in the cylinder may appreciably affect the starting. For instance, a plug with a short thread screwed into a deep valve cap may result in the points being contained in a pocket which is not readily reached by the mixture. The remedy is to alter the valve cap so that the points project into the main part of the combustion

chamber. Special long-thread plugs can be obtained (not a service store). Nearly all plugs nowadays have a metric thread.

83. *Magneto ignition systems*

1. **The high-tension magneto system** consists of the following essential parts :—

   i. An *electric generator*, with permanent field magnets, giving an alternating current.
   ii. An *induction coil*, both primary and secondary windings being wound on the armature.
   iii. A *contact-breaker* to interrupt the generator primary circuit.
   iv. A *distributor*, to distribute high-tension current to the sparking plugs:

2. **The generator** consists of an H armature, Pl. **63**, Fig. **1**, built up of laminated soft iron plates and wound with insulated copper wire. It revolves between laminated soft iron pole-pieces attached to the permanent magnets. The clearance between the armature and pole-pieces is very small.

Imagine the armature to be revolving as shown by the arrow. When in position P, the magnetic lines of force take the easiest magnetic path, as shown, and none of the windings cut the lines of force. There is, therefore, no E.M.F. generated.

From P to Q the lines of force are pulled round with the revolving armature, the conductors of which only cut a few stray lines of force. As the gap between C and D is diminished, more lines of force are cut by moving conductors until the position R is reached.

At this point, the flux through the coil is negligible and the E.M.F. generated a maximum. The maximum value of the current occurs later in the position shown approximately at *S*, at low speeds.

There are two positions for maximum current in one revolution of the armature, the second one being when point B leaves point E.

The voltage curve is shown on Pl. **63**, Fig. 2. The current curve is similar but not exactly in phase (lags).

3. **The armature.**—The armature winding which *generates* the low-tension voltage, is known as the *primary winding*, and consists of a few turns of relatively thick wire. Wound on the same armature and over the primary winding is the secondary winding, consisting of several thousand turns of very fine insulated wire. Therefore, an induction coil is wound on the armature. Any change of current in the primary winding will *induce* an E.M.F. in the secondary winding which, added to the voltage generated in this winding,

PLATE 63.

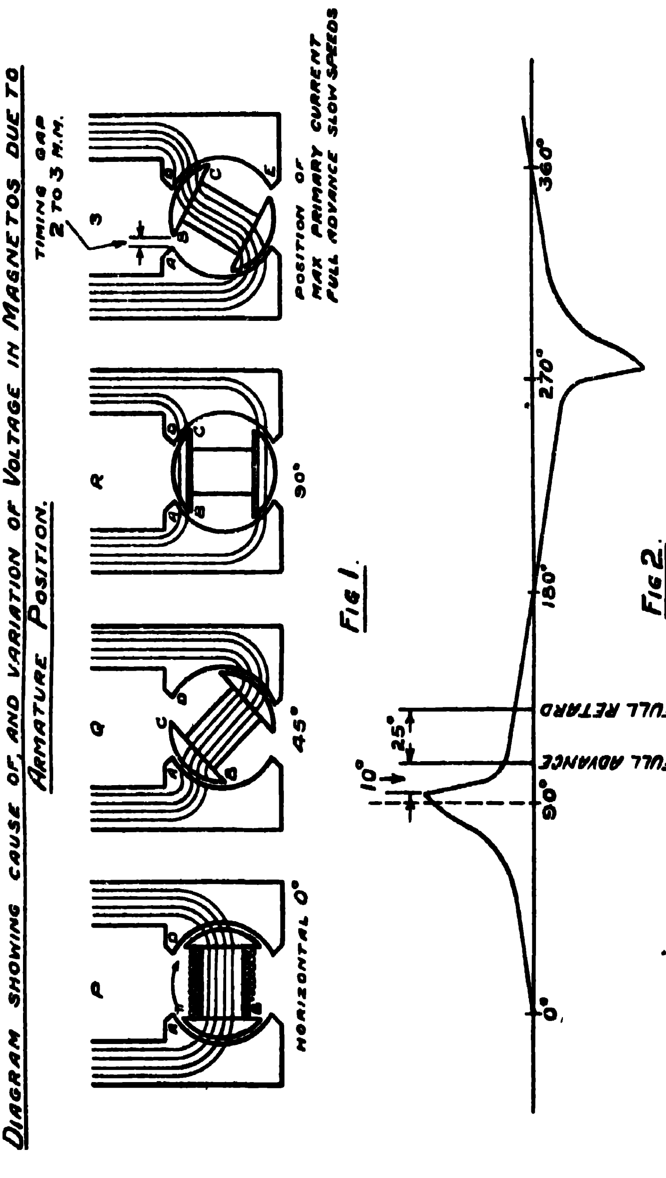


FIG 1.

FIG 2.

produces the spark. The magnitude of the *induced* voltage in the secondary winding depends on :—

i. The ratio of turns of wire in the secondary to those in the primary (a matter of design).

ii. The rate of change of current in the primary.

To obtain the maximum *induced* voltage in the secondary, the current in the primary is reduced from its maximum to zero by breaking the primary circuit as quickly as possible.

4. **The contact-breaker** is the device for breaking the primary circuit, Pl. **64**, Fig. 1.

It revolves with the armature, being keyed to the spindle, and consists of two points, P, one fixed and the other at the end of a pivoted·bell crank lever. This lever is normally pressed by a spring, so that the two points are in contact. (The contact points are now made of *tungsten*, which is much cheaper than platinum, used in early magnetos.)

The contact-breaker revolves in a cam ring, the cams being so placed that the bell crank lever rides up them at the points of maximum current in the primary. This separates the points quickly and so breaks the primary circuit.

The contact-breaker is keyed to the spindle in such a position that the *timing gap* AB, S of Fig. 1, Pl. **63**, between the leading edge of the fixed pole-piece and the trailing edge of the H armature is about 2 or 3 mm., when the points begin to separate, the spark lever being in the *full advance* position. (*See* para. 3, above.)

5. **The primary circuit** is shown diagrammatically on Pl. **65** and Pl. **64**, Fig. 3, which should be read in conjunction.

One end, *a*, of the primary winding is connected to the armature core. The other end, *b*, is taken, *via* one side of the condenser, and thence through an insulated bush in the armature spindle to the long screw, *d* (Pl. **65**), which holds the contact-breaker to the armature, and which makes contact with the fixed point; *e*, which is insulated from the main body of the contact-breaker. The primary circuit continues through the moving point, *f*, through the bell crank lever and its spring, *g*, back to the metallic portion of the contact-breaker, and thence through the armature spindle to the armature and point, *a*.

The other side of the condenser is connected with the moving point, through the frame (or earth), so that the condenser is connected across the two points.

6. The object of the condenser is two-fold :—

i. To reduce arcing at the points when the break is made, and thus save wear and tear of the points.

ii. By stopping the formation of the arc, to cause a more rapid break of the primary (an electric arc once formed acts as a conductor).

7. The secondary circuit and distributor.—One end of the secondary coil is connected to the primary, at *b*, and thence to the armature core. The other end is led out to the metal collector ring, *h*, and the circuit is led thence by the carbon brush, *j*, through a metal rod to the revolving carbon brush, *k*, on the distributor, which is driven at half the speed of the armature. The distributor brush, *k*, makes contact in turn with the segments, *l*, from which the current is led in turn along insulated cables to the insulated terminals of the sparking plugs. The body of the sparking plug is screwed into the engine, which is in metallic contact with the frame of the magneto, and therefore, with the armature and point, *a*, to which one end of the secondary circuit is attached (through the primary in this case).

At the moment of *break* in the primary circuit, the induced voltage in the secondary, added to the generated voltage, is high enough to spark across the plug points.

In magnetos for single-cylinder engines no distributor is required, the current being led direct from the collector-brush, *j*, to the single sparking plug.

In two-cylinder magnetos the distributor is often combined with the collecting ring, there being two collector-brushes, *j*.

Some distributors have a revolving spark gap electrode in the place of the revolving carbon brush. This puts a small series air gap in the circuit, and therefore a higher voltage is required, but the prevention of leakage from the secondary while the voltage is building up, more than compensates for this.

8. The safety spark gap on the high-tension circuit is in parallel between the lead from the collecting brush, *j*, and the frame of the magneto. Its object is to prevent excessive voltages, which might pierce the insulation of the secondary winding, from being produced therein should a lead become detached from its plug whilst the engine is still running. The distance between the points of the safety gap should, therefore, be greater than that between plug points.

9. Earthing brush.—It will be seen that the secondary circuit has to pass from the secondary winding, through the primary winding to the armature spindle, and thence to earth. To facilitate this, and to obviate sparking at the ball bearings, the contact-breaker is fitted at the back with an *earthing-brush* which rubs against the frame of the magneto.

10. Earthing switch.—In order to switch off the spark, the primary circuit is short-circuited by a switch which connects the fixed platinum or tungsten point to the frame of the engine. This prevents the current from being broken when the points are separated (as shown on Pl. **64**).

11. **Timing the magneto to the engine** is effected as follows :—

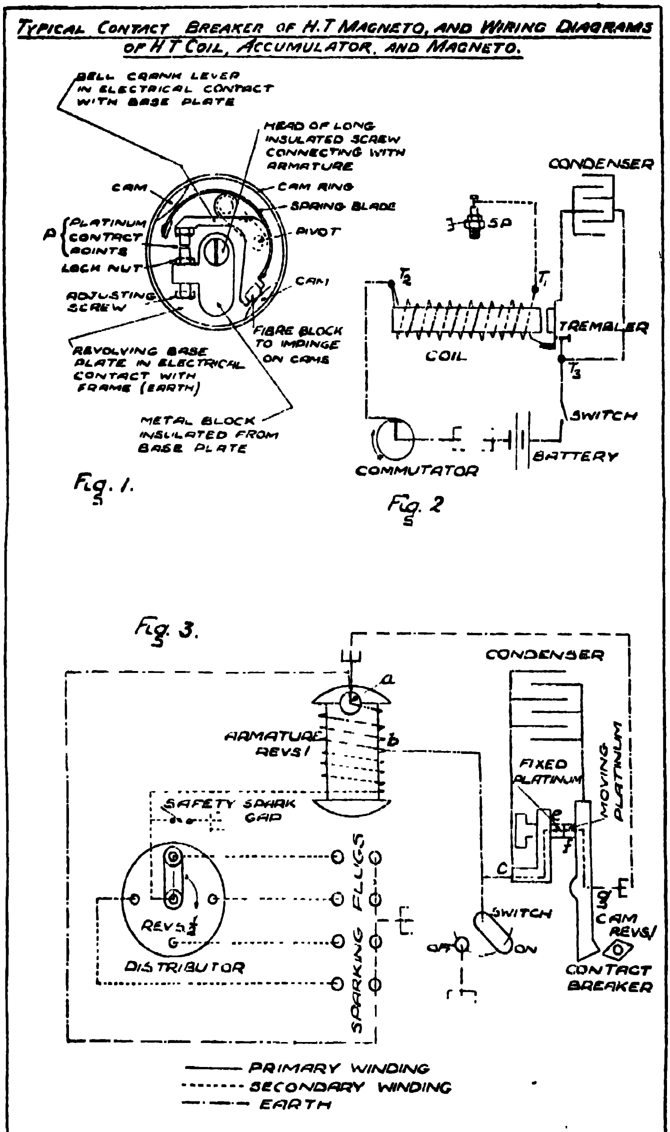
i. *When the ignition point is not marked on the flywheel.* Fully *retard* the magneto. Turn the engine until one piston is at inner dead centre on the compression stroke. Note the direction of rotation of the magneto and turn it forward until the points are just about to break. Then couple up the magneto and engine in these relative positions. Ascertain from examination of the distributor which of the high-tension leads radiating from it is connected with the high-tension circuit through the distributor brush, *k*, and connect that lead to the sparking plug of the cylinder being dealt with. Then connect up the other plugs in accordance with their firing sequence. This can be done by examination of the magneto distributor and the valves of the engine.

The normal firing sequence for four-cylinder engines is 1, 3, 4, 2, number 1 cylinder being that farthest from the flywheel in normal engines. An uncommon alternative is 1, 2, 4, 3. Six-cylinder engines usually fire in the order 1, 5, 3, 6, 2, 4. To check firing order, watch the order of lift of inlet or exhaust valves.

ii. *When the ignition point is marked on the flywheel,* turn it till this mark is uppermost (in line with centre of cylinder bores). The pistons of No. 1 and No. 4 (in four-cylinder engines) are then approaching inner dead centre. Turn the engine so that No. 1 is on the compression stroke. Place the magneto in the *fully advanced* position and connect to engine. Then proceed with distributor, leads, &c., as in (i).

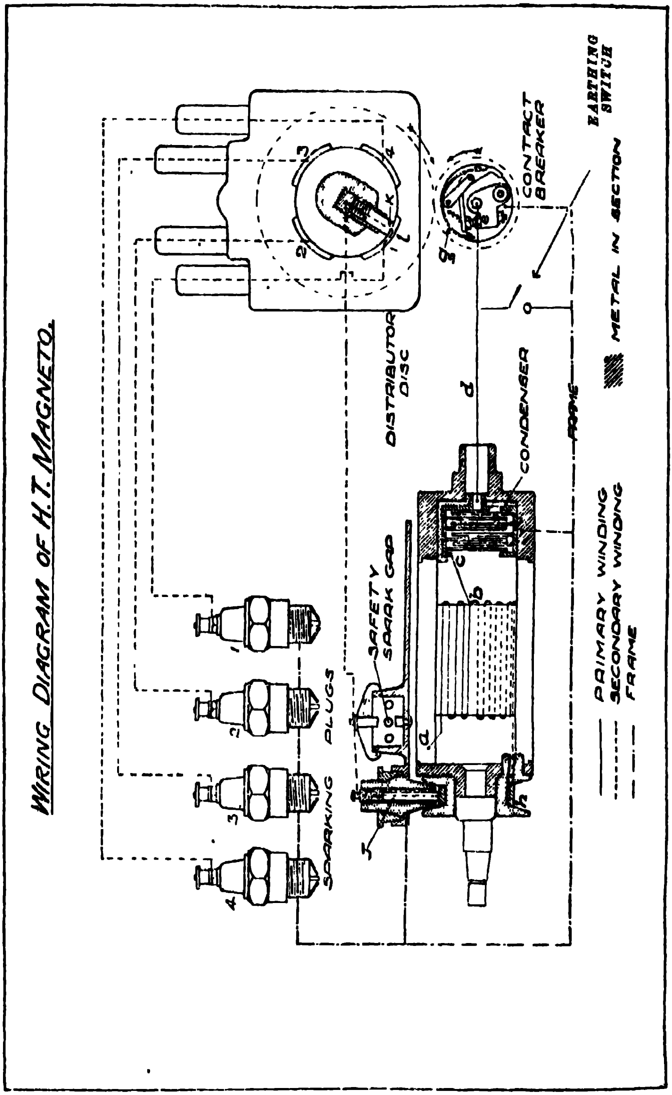
Some magnetos have quickly adjustable couplings, which render accurate magneto timing easier. A common method is the vernier ring. A loose fibre ring has, say, 17 teeth on one side engaging with a similar ring of the engine, and 18 teeth on the other, engaging with an 18-tooth ring keyed to the magneto. To advance the magneto timing slightly, withdraw magneto together with fibre ring. Turn the magneto and fibre ring slightly forward so that the ring will re-engage with the engine one tooth farther forward, *i.e.* advanced by $\frac{360}{17}$ degrees (on the magneto shaft). Now withdraw again, this time leaving the fibre coupling on the engine. Turn the magneto back slightly so that it will re-engage with the fibre ring one tooth back, *i.e.* retarded by $\frac{360}{18}$ degrees. The net result is an advance of $\frac{360}{17} - \frac{360}{18}$ degrees of the magneto on top of whatever the timing was before (about 1 degree).

PLATE 64.



TYPICAL CONTACT BREAKER OF H.T MAGNETO, AND WIRING DIAGRAMS OF H T COIL, ACCUMULATOR, AND MAGNETO.
BELL CRANK LEVER IN ELECTRICAL CONTACT WITH BASE PLATE
HEAD OF LONG INSULATED SCREW CONNECTING WITH ARMATURE
CAM
CAM RING
SPRING BLADE
P
PLATINUM CONTACT POINTS
PIVOT
LOCK NUT
CAM
ADJUSTING SCREW
FIBRE BLOCK TO IMPINGE ON CAMS
REVOLVING BASE PLATE IN ELECTRICAL CONTACT WITH FRAME (EARTH)
METAL BLOCK INSULATED FROM BASE PLATE
Fig. 1.
CONDENSER
SP
T2
T1
TREMBLER
COIL
T3
SWITCH
COMMUTATOR
BATTERY
Fig. 2
Fig. 3.
CONDENSER
a
ARMATURE REVS 1
b
FIXED PLATINUM
MOVING PLATINUM
SAFETY SPARK GAP
e
f
c
g
SPARKING PLUGS
SWITCH
ON
CAM REVS 1
REVS ½
G
DISTRIBUTOR
CONTACT BREAKER
PRIMARY WINDING
SECONDARY WINDING
EARTH

PLATE 65.


WIRING DIAGRAM OF H.T. MAGNETO.
DISTRIBUTOR DISC
CONTACT BREAKER
EARTHING SWITCH
METAL IN SECTION
CONDENSER
FRAME
SAFETY SPARK GAP
SPARKING PLUGS
PRIMARY WINDING
SECONDARY WINDING
FRAME

12. **Advancing and retarding the spark.**—The necessity for timing the spark was explained in Sec. **82**, para. 4, on the assumption that the intensity of the spark was constant, but it will be understood that the more intense the spark the quicker will the combustion be completed.

It was further pointed out in para. 2 that the maximum value of the current occurs later than the E.M.F. This is due to the reactance of the windings, and as this is proportional to the speed, the angle of lag will increase as the speed rises. Therefore, if the current is always to be broken when at its maximum value the contact-breaker must be timed to function later as the speed increases.

It should also be noted that although the voltage increases with the speed, so also does the reactance, and consequently the current at 2,000 r.p.m. is probably not more than double its value at 100 r.p.m.

These points should not be lost sight of when considering the effects of advancing or retarding the spark. A traverse of 25° to 30° between *full advance* and *full retard* is usually provided in rotating armature magnetos (half this value in polar inductor magnetos).

As a rule, in the *fully advanced* position the break is arranged to occur when the armature is in the position shown at *S* on Pl. **63**, Fig. 1, the *timing gap* AB being about 2 to 3 mm. in most magnetos (but may be as low as 0·5 and as great as 4 mm. in some designs). This ensures that the maximum intensity of spark will be obtained at *slow speeds* in the fully advanced position, which is therefore the best for starting (but see instructions in Sec. **87** for starting by hand).

13. **Direction of rotation.**—Magnetos are made for one definite direction of rotation, which is generally marked on them by an arrow. It is customary to describe the direction of rotation as clockwise or counter-clockwise when looking from the driven end (*i.e.* the end remote from the contact-breaker).

Referring to Pl. **63**, Fig. 1, it is clear that a magneto running counter-clockwise should have its contact-breaker keyed to the spindle in such a way that point C would be just leaving point D when the points begin to break. The gap CD would then be the *timing gap* of 2 to 3 mm. with spark *fully advanced*.

The direction of rotation of magnetos can be changed either by :—

i. Cutting a new key-way in the spindle in such a position that this is effected.

ii. Altering the position of the cams on the cam ring (they are sometimes made detachable for this purpose), or of the cam ring itself.

At the same time care must be taken that the brush, *k*, on Pl. **65**, is still making contact with the correct segment, *l*,

when the points break from the full-advanced to the full-retard position. If it is not, the meshing of the distributor gear wheels must be altered to correspond. In many cases there are two pairs of adjacent teeth spotted on these wheels, marked R and L for right and left hand rotation respectively.

14. **Care of magnetos.**—

i. Keep dry. Damp breaks down the insulation and weakens the spark.

ii. Oil very seldom. Oil on the tungsten points results in bad contact in the primary and a weak or no spark.

iii. Keep the tungsten points clean and even. They can be cleaned by drawing a piece of paper between them when closed under the action of the spring. They can be evened up by dismantling and rubbing on fine emery cloth laid on a flat surface.

iv. Adjust the tungsten points to break at the correct armature position. Maximum opening should be 0·012 in.

v. Keep the distributor quite clean by rubbing the fibre and copper segment occasionally with a rag soaked in petrol. Dirty segments result in leakage of the high-tension current to the other segments and plugs.

vi. Watch the carbon brushes for wear and broken springs and renew them when necessary.

vii. *Never separate armature from magneto without first putting a keeper on the magnets.* Do not remove the keeper till armature is in place again.

15. **Other types of magneto that may be met with.**—

i. *A high-tension trip magneto* is sometimes fitted on single-cylinder engines running at speeds up to 600 revolutions per minute. Its object is to obtain a good spark for starting, and for running afterwards at comparatively low speeds; this is achieved by revolving the armature slowly through about 22 degrees from the symmetrical position against two strong spiral springs, which pull it back through the maximum position *very quickly* when the trip takes place.

The high-tension trip magneto illustrated in Pl. **66**, Fig. 6, is actually a "*sleeve*" inductor type machine, in which the armature remains stationary. Between the armature and the poles there is an annular space in which an iron shield or sleeve is rotated or oscillated. This machine is similar in principle to the polar inductor magneto described in the next paragraph.

ii. *Polar inductor magnetos* are those in which the armature and both windings are stationary, and the soft iron inductors,

attached to a non-magnetic spindle, are the only parts which revolve.

Referring to Pl. **66**, Figs. 1 to 4, the inductors *NS* which are virtually extensions of the permanent magnets *ns*, revolve between the soft iron extensions *P.P.* of the iron core *C* on which the primary and secondary windings are placed. The flux changes direction through the coil in passing from the position shown in Fig. 1 to that shown in Fig. 3. The maximum value of the E.M.F. occurs in the position shown in Fig. 2 when the flux through the coils is practically negligible. The current lags behind the E.M.F. as explained in the case of the ordinary magneto, and therefore the primary circuit is arranged to break when the *timing gap A.B.* (Fig. 3) is from 0·5 to 1 mm. with the timing lever *fully advanced.*

iii. *Low-tension magnetos* are still sometimes found on gas engines and certain types of small farm petrol engines. They consist of a magneto, provided with a primary winding only, one end of which is earthed and the other end is led to the fixed insulated terminal of the make-and-break device which is in the cylinder, Pl. **66**, Fig. 7, and which is actuated by a rod off the half-time shaft.

The main points to note are :—

i. The sparking points, which give an *arc* when moved apart under low voltage, must be quite clean and dry.

ii. The break must be adjusted to take place at the same time as the magneto armature (whether of the trip or other type) passes the position of maximum current, *see* Sec. **83**, para. 2.

The connections are similar to those in the ordinary revolving armature magneto.

Advance and retard are effected by pivoting the core *C* with its extensions *P.P.*, which carry the contact-breaker, and the break always occurs at the position of maximum current.

The advantages of this type over the ordinary H.T. magneto are :—

i. It is easier to make. The windings do not revolve and are less liable to become disconnected.

ii. A greater range of advance and retard can be given, the spark intensity being always a maximum.

iii. More sparks per magneto revolution can be obtained than with the ordinary magneto (which is limited to two sparks per revolution). This is done by increasing the number of inductors, and may be an advantage in multi-cylinder engines.

16. The impulse starter is a device which converts an ordinary H.T. magneto into one of the trip type for starting,

PLATE 66.

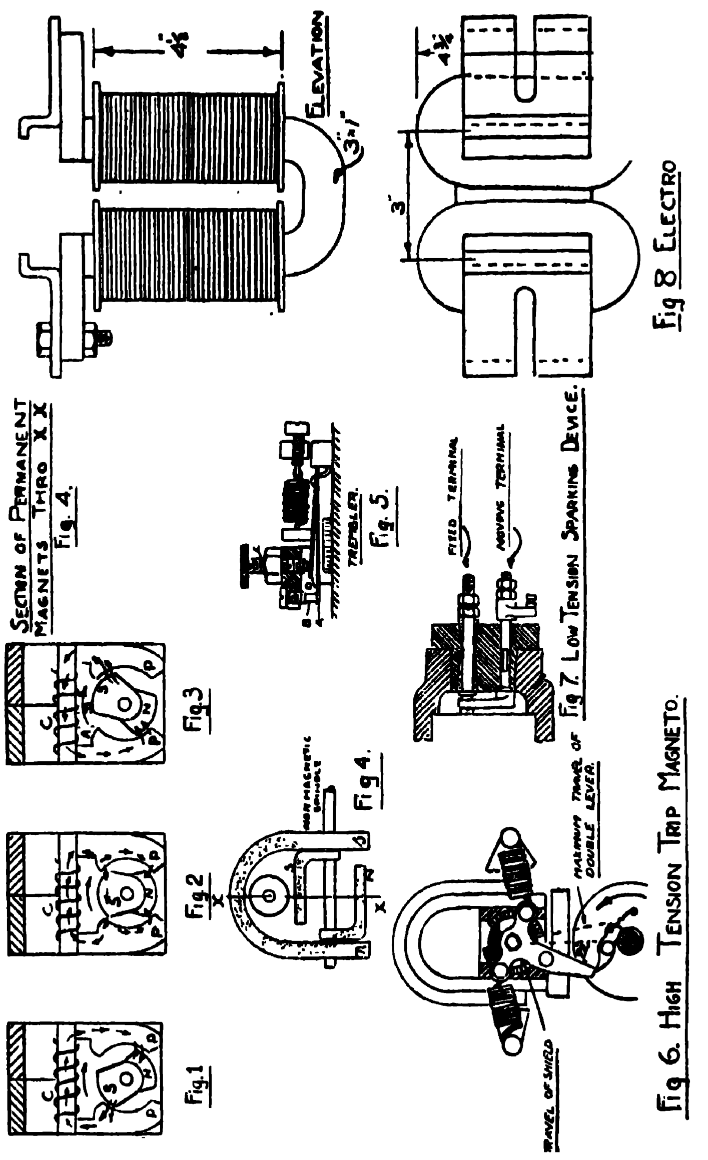


Fig 1
Fig 2
Fig 3
Fig 4.
Section of Permanent Magnets thro X X Fig. 4.
Non magnetic spindle
Trembler. Fig. 5.
Fixed terminal
Moving terminal
Fig 7. Low Tension Sparking Device.
Elevation
Fig 8 Electro
Maximum travel of double lever.
Travel of shield
Fig 6. High Tension Trip Magneto.

thus ensuring a higher armature speed than can be given by directly coupling the magneto to a part of the engine turned by hand, and, therefore, enabling the spark lever to be retarded, whilst at the same time obtaining a good spark.

During the latter half of the compression stroke the armature is held stationary by a clutch, the spring meanwhile winding up. At the correct moment the clutch is automatically released, and the spring causes the armature to catch up with a jerk, thus giving a full-power spark, however slowly the engine is turned over. As soon as the engine is running, the whole device is automatically cut out of action and the magneto works in the ordinary way.

84. *Faults in magneto ignition systems*

1. If a failure of the magneto ignition system is suspected, the following table shows how the fault should be traced, and its remedy.

Symptom	Reason	Remedy	Remarks
i. *No spark at plug at starting.*	Faulty plug due to :—		The fault can be quickly traced to plugs if a good lead is removed from plug and tested for spark when held 1/8 in. (not more) from engine. *See* Sec. 82, para. 3.
	(*a*) Dirty shorting points.	Clean with petrol.	
	(*b*) Interior carboned up or oily.	Clean.	
	(*c*) Cracked insulating porcelain.	Replace plugs.	
	(*d*) Points set too wide.	Adjust to ·025 in.	
	(*e*) Faulty H.T. leads.	Replace.	
	(*f*) Earthing switch shorting primary.	Disconnect or switch off.	
ii. *No spark at starting* and no shock given when the magneto is turned by hand and one of the H.T. terminals felt.	Faulty magneto due to :—		
	(*a*) Bell crank lever stuck up through damp or a faulty spring.	Thin down stud with emery paper. Replace spring.	Common in wet weather.
	(*b*) A disconnection somewhere in the primary or secondary circuit or a short circuit.	*Repair.	
	(*c*) One of the carbon brushes not making contact.	Renew.	

Symptom	Reason	Remedy	Remarks
iii. *Weak spark at starting* (not sufficient to start the engine when under compression).	(*a*) Faulty plug.	Clean or replace.	*See* remarks to (i), above.
	(*b*) Magnetism of magnets weak.	*Re-magnetize.	
	(*c*) Damp magneto.	*Dry out coils in a slow oven.	
	(*d*) Dirty tungsten points.	Clean with paper and petrol.	
	(*e*) Pitted and uneven tungsten points.	True with a very smooth file or emery cloth.	
	(*f*) Tungsten points breaking too much or too little.	*See* para. 3.	
Accompanied by sparking at the tungsten points.	(*g*) Pierced condenser or a connection to condenser broken.	*Renew condenser or replace lead.	
	(*h*) Magneto too far retarded.	Advance.	
	(*j*) Dirty distributor.	Clean.	
iv. *Magneto sometimes gives a spark, and sometimes does not.*	(*a*) A faulty plug.	Replace.	
	(*b*) A faulty lead.	Replace.	
	(*c*) An internal disconnection either between unearthed ends of H.T. winding or L.T. winding.	*Repair.	

The repairs marked * require the services of an electrician.

2. Unless special facilities exist, it is not desirable that repairs entailing the unwinding of the secondary or primary should be undertaken by military labour. In peace time, a civil firm should be given the work; in war time, a spare should be demanded.

3. With regard to fault iii. (*f*) in para. 1. The correct adjustment of the tungsten points is most important. Makers normally lay down that the maximum break should be adjusted to ·012 inch, and set the contact breaker relative to the armature to suit this.

Referring to Pl. 64, Fig. 1, if the points can normally break more than this the adjusting screw must be screwed farther out, and in this case the fibre inset on the bell crank lever will come earlier on to the cam, and the break will occur earlier (*i.e.* before the maximum current position of the armature, when the spark is *fully advanced*). Trouble will then be experienced in starting, unless the spark lever is ***retarded.***

If the break is allowed to become too small, from whatever cause (*e.g.* wear of cams or fibre inset), the points will break after the maximum current position, with the spark lever at full advance, and starting will be rendered very difficult.

4. In dismantling a magneto, the magnets, if removed, should be marked so that they can be reassembled in exactly the same relative position to the pole-pieces as before, but they should only be removed in very exceptional circumstances.

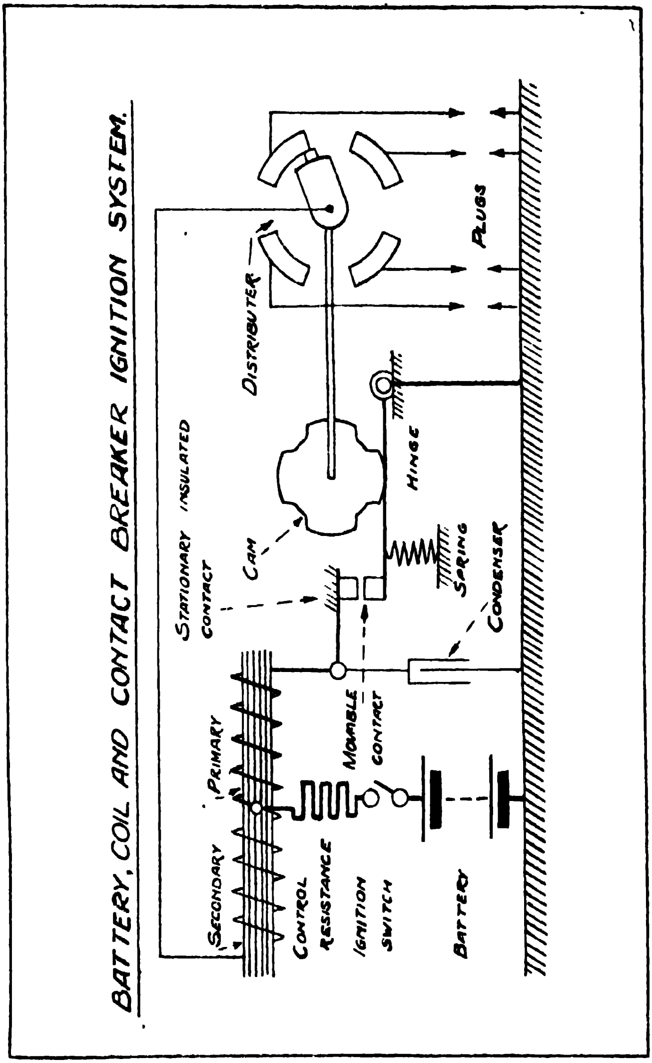
Remagnetizing.—The permanent magnets of a magneto may require boosting up occasionally. To do this the magnets should be placed on the poles of a strong electromagnet (Pl. **66**, Fig. 8), care being taken to ensure the correct polarity. When the permanent magnets and electromagnet are in contact, *and not before*, the armature or keeper should be removed. The current should then be switched on and off several times for periods of a few seconds, the magnets being tapped lightly while the current is on. Then replace armature or keeper *before* removing the magnets from the electromagnet. A suitable electromagnet can be constructed from a 15-in. length of 3-in. by 1-in. *wrought-iron* bar bent into " U " shape with 3-in. centres, and wound with half a pound of 35 S.W.G. double silk covered copper wire on each limb. This coil has a resistance of about 370 ohms and is suitable for connection to a 230-volt supply.

85. *Battery and coil ignition systems*

1. **Battery, coil and contact-breaker system.**—Pl. **67** shows the electric circuit in the ordinary coil ignition system, which has become so popular in cars. The general idea is much the same as in the magneto, but the primary current is here supplied by an accumulator, usually of 6 or 12 volts. The armature and coils are stationary and are often mounted away from the engine. The circuit is made and broken by a contact-breaker, with condenser, just as in a magneto. The chief differences in the electrical circuit are that the ignition switch is in series with the primary circuit and that a control resistance is inserted in the primary to limit the current. The resistance of the primary being only about 0·5 ohms without a control resistance, it will be seen that if the engine were stopped with the contacts " making " and the switch left " on," the battery would discharge itself heavily and possibly overheat the coil.

Owing to the longer time available for building up the primary current at low speeds, coil ignition usually gives a better spark at starting than at high speeds. The starting spark is superior to that of a magneto, the high speed spark

PLATE 67.


BATTERY, COIL AND CONTACT BREAKER IGNITION SYSTEM.
SECONDARY
PRIMARY
CONTROL RESISTANCE
IGNITION SWITCH
BATTERY
MOVABLE CONTACT
STATIONARY INSULATED CONTACT
CONDENSER
SPRING
CAM
HINGE
DISTRIBUTER
PLUGS

inferior. The better starting spark is a decided advantage, and a further advantage is that there is no limit to the range of advance and retard, as this has no effect on spark strength as in a magneto.

From the service point of view the fact that starting the engine depends absolutely on the accumulator being to a certain degree charged, renders all coil ignition systems somewhat unsatisfactory. Combined with a magneto as a stand-by for starting, and a generator for keeping the battery charged, the system is excellent, although somewhat complicated and expensive.

2. **Battery and trembler coil system.**—This system, which must be clearly distinguished from the battery, coil, and contact-breaker system, is normally used only for starting heavy engines, say, upwards of 40 H.P., which cannot be cranked fast enough in cold weather to start with magneto alone. The system, which is normally used in conjunction with a magneto, is switched off when the engine has gathered speed and the magneto is working properly. It requires a separate set of sparking plugs and high-tension leads, and thus is somewhat complicated. Provided, however, that there is a charge in the battery, it provides the most infallible method of starting known. So efficacious are the sparks provided, that if a warm engine is placed just over top dead centre and the trembler switched on, the engine will often start without any cranking at all. The mixture remaining in the cylinder from the previous run makes this possible, provided the engine was stopped by switching off only, and is in good condition.

The battery and trembler coil system for a single-cylinder engine is shown diagrammatically on Pl. **64**, Fig. 2.

The trembler, Pl. **66**, Fig. 5, consists of a piece of soft iron, A, on a pivoted steel spring, which is normally forced up against the screw, B, so that platinum points on the screw, C, and the trembler, D, are in contact.

When the commutator completes the circuit, current flows in the primary coil (Pl. **64**, Fig. 2), converts the iron core into an electro-magnet, and causes the soft iron piece on the trembler to be attracted towards it, thereby separating the platinum points and breaking the circuit suddenly. This induces a high E.M.F. in the secondary winding, which causes a spark at the plug.

The H.T. circuit is from T_1 to the plug, across the gap to earth, thence to the commutator, to T_2, and back through the secondary coil to T_1.

Directly the platinum points are broken, current ceases to flow in the primary, and the *electro-magnet ceases to attract the trembler, which flies back to its first position,*

thereby causing contact at the platinum points and current to flow again.

The whole process is repeated several times whilst the commutator completes the circuit, a succession of sparks being obtained at the sparking plug.

There are three terminals on the coil box.

The actual connections are :—

i. One terminal of the battery to the frame, and the other to the battery terminal on the coil box, T_3.
ii. The plug is connected to the plug terminal on the coil box, T_1. This plug terminal is usually marked S on the box, meaning secondary circuit.
iii. The commutator is connected to the other coil box terminal, T_2.

For four-cylinders a H.T. distributor (similar to that used for a magneto) is also required.

The special adjustments for this type of ignition are :—

i. The battery must deliver the voltage for which the coil is designed.
ii. The platinum points must be clean and even (this necessitates frequent cleaning), and the screw so adjusted that the trembler will oscillate strongly when the current flows.

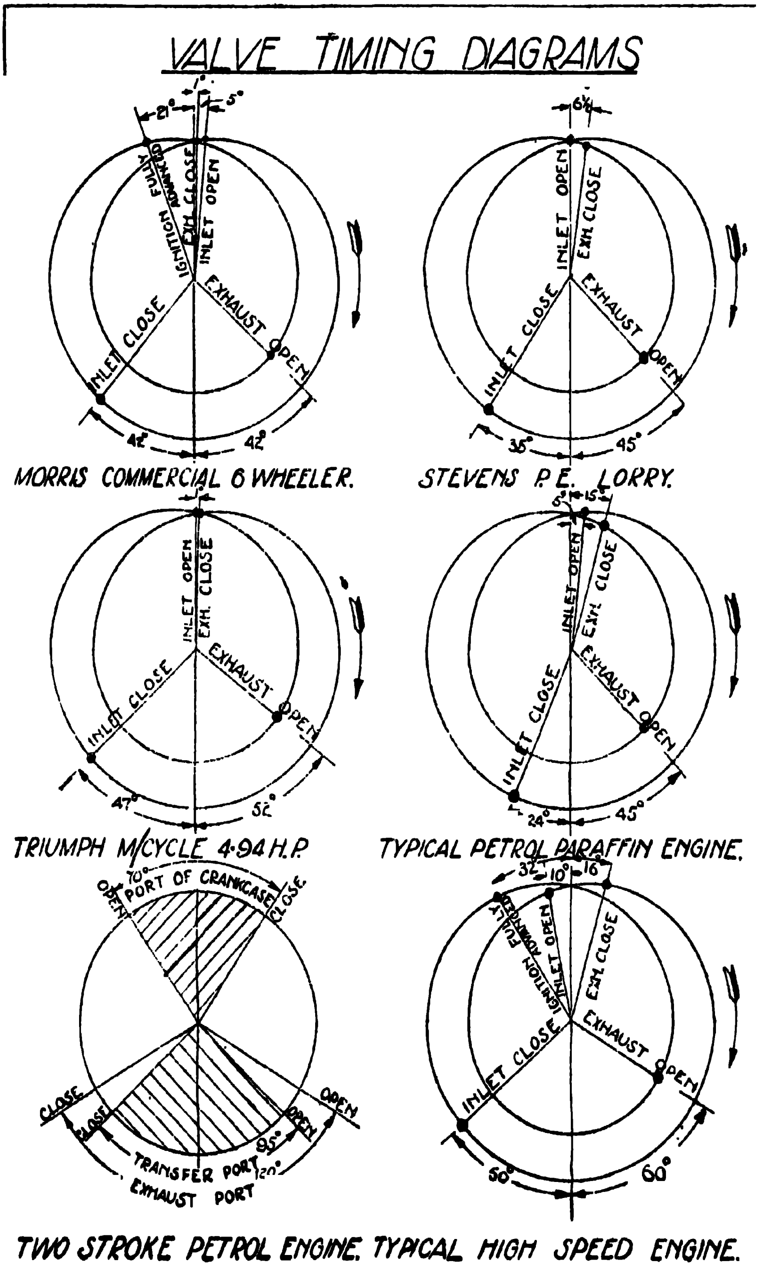
In timing a trembler system to an engine, care should be taken to see that on full retard the piston is at least at inner dead centre and preferably about 5° after, or nasty back-firing may occur on starting. Care must be taken not to get a shock from a battery and trembler system. Though not really dangerous, those who dislike a magneto shock will find one from a good trembler quite stunning in comparison.

86. *Valve timing in petrol engines*

1. The principles of valve timing as discussed in Chapter XIII hold good for petrol engines. Owing to higher speeds, however, and the fact that several cylinders may be drawing mixture from one carburettor, there are differences.

2. Pl. **68** shows the valve timings adopted in several very different petrol engines. It will be noticed that the road vehicle engines all have the exhaust opening points about the same, *i.e.* about 45 degrees before *outer dead centre.* Although this precise angle is in itself not very important, the fact that it is nearly the same in all road vehicle engines may be made use of in retiming such an engine, whose correct timing is not known. It is a common bad practice to retime in such cases by making the inlet valve open at *inner dead*

PLATE 68.


VALVE TIMING DIAGRAMS
1°
21°
5°
IGNITION FULLY ADVANCED
EXH. CLOSE
INLET OPEN
INLET CLOSE
EXHAUST OPEN
42°
42°
MORRIS COMMERCIAL 6 WHEELER.
6¼
INLET OPEN
EXH. CLOSE
INLET CLOSE
EXHAUST OPEN
35°
45°
STEVENS P.E. LORRY.
INLET OPEN
EXH. CLOSE
INLET CLOSE
EXHAUST OPEN
47°
52°
TRIUMPH M/CYCLE 4·94 H.P.
6°
15
INLET OPEN
EXH. CLOSE
INLET CLOSE
EXHAUST OPEN
24°
45°
TYPICAL PETROL PARAFFIN ENGINE.
70°
PORT OF CRANKCASE
OPEN
CLOSE
CLOSE
CLOSE
OPEN
OPEN
95°
120°
TRANSFER PORT
EXHAUST PORT
32
10°
16
IGNITION FULLY ADVANCED
INLET OPEN
EXH. CLOSE
INLET CLOSE
EXHAUST OPEN
50°
60°
TWO STROKE PETROL ENGINE. TYPICAL HIGH SPEED ENGINE.

centre. This may result in the timing being as much as 15 degrees out, a greater error than usually occurs by assuming the exhaust opening point to be 45 degrees before *outer dead centre*, and using that point for timing.

3. Most four-cylinder engines drawing from one carburettor have late opening inlet valves so that any two inlet valves shall not be open together for longer than necessary. Otherwise the mixture quantity to the cylinders would be even more upset than it already is by the uneven surging which goes on in the induction system. The uneven lengths of pipe to each cylinder and the unsymmetrical arrangement are the main causes of the surging, which not only affects quantity feed to cylinders, but also mixture strength.

4. The overlap of exhaust closing and inlet opening, which is common in constant speed engines, is dying out in petrol engines for road use. It is found that such overlap only gives a useful scavenge effect at definite speeds. It is still made good use of in aero engines and racing engines.

5. The port timing of two-stroke petrol engines should not be altered by filing the ports.

87. *Starting petrol engines*

1. Make sure that the crankcase is filled to the correct level with oil. Most makers fit either an oil-level gauge or two taps, which indicate the highest and lowest permissible oil levels. It is good practice to pour a small quantity of fresh oil into the crankcase before starting up from cold.

2. Ascertain that the radiator is full of water.

3. Turn on the petrol. (Sometimes it may be necessary to *flood* the carburettor by lifting the float chamber needle valve.)

4. With the ignition switched off turn the starting handle about four turns.

The amount of throttle opening given will vary with the carburettor fitted. With Zenith carburettors, or any type having a special starting jet, the throttle should be practically closed.

In no case should it be more than one quarter open.

5. Switch on the ignition. If coil and accumulator ignition is fitted *retard* the spark *well*. If magneto ignition is fitted, it is best to *retard* the spark *slightly*, unless the engine is known; but it must be borne in mind that the best spark, and, therefore, easiest starting, is obtained with the magneto in the full advance position.

With magneto ignition, a poor spark is largely responsible for any difficulty at starting that may be experienced.

6. Grasp the starting handle with the right hand in such a way that an upward pull, not a downward push, can be given. *The thumb should be on top of the handle, not below it,* in order to avoid an accident due to the engine back-firing.

7. Give a sharp upward pull to the handle and the engine should start. It will often be found necessary to swing the handle (*i.e.* to turn it round and round) in order to obtain sufficient speed to obtain a good enough spark.

8. In cold weather, petrol may not vaporize well at starting. By flooding the carburettor well and stopping up the air inlets with a rag or any device which may be fitted by the makers, it will usually be possible to start the engine. If the engine is hot, strangling should not be resorted to, or the mixture may be too rich to fire.

If this is not effective, resort should be had to :—

i. Filling the radiator with hot water.
ii. Heating the inlet pipe with a rag soaked in hot water.
iii. Injection of petrol into the cylinders.

9. Immediately the engine starts to fire regularly, reduce the throttle opening, if necessary, so that the engine does not race. Allow the engine to warm up before bringing on the load. When on load, *advance the spark.*

10. If an oil tell-tale or an oil pressure gauge is fitted, make sure that it is working.

11. *Starting two-stroke petrol engines.*—The same rules apply as for four-strokes, but one or two hints may be useful.

i. Owing to the large surfaces of the crankcase, cold two-stroke engines usually require thorough carburettor flooding, unless they were previously stopped by strangling the carburettor.

ii. It may sometimes happen, due to leaving the petrol turned on, to a flooding carburettor and to the design, that much liquid petrol may have accumulated in the crankcase while the engine has been idle. This often most effectively prevents starting. To avoid it, always see that the petrol is turned off when stopping.

iii. Never flood or strangle when restarting a hot two-stroke engine or the mixture may become too rich to start.

iv. When an engine has had time to cool down before restarting, it is a good plan to stop it by strangling the air intake. This makes for a very easy subsequent start from cold. Do not stop by this means if the engine is to be restarted before cooling down.

12. *Reversing direction of rotation of a two-stroke petrol engine.*—This involves the alteration of the ignition system and timing, so that the spark occurs in the symmetrical position on the other side of the inner dead centre. The first step will be to make the magneto work in a reverse direction (*see* Sec. **83**, para. 13). Afterwards it is retimed to the engine in the usual way.

The starting handle dogs may need to be altered, so that the handle will work in the reverse direction.

88. *Petrol engine faults*

The following table indicates how engine faults may be traced by the attendant. It is assumed that the engine is correctly assembled, and that water, oil, and petrol are in the correct quantities and receptacles :—

This section must be read in conjunction with Sec. **84**, on magneto faults.

Symptom	Cause	Remarks
i. Engine fails to start or is difficult to start.	Faulty fuel supply owing to :—	
	Choked petrol pipe	Remedy obvious.
	Air-lock in petrol pipe	Remedy obvious.
	Choked jet	Remedy obvious.
	Water in petrol ..	Remedy obvious.
	Failure to vaporize	Flood, inject, stop air supply, heat inlet pipe, and heat plugs.
	Mixture wrong.	—
	Air leaks due to loose plugs, valve caps, induction pipe, valve guides, &c.	—
	Throttle too wide open.	Never more than ¼ open.
	Mechanical faults owing to :—	
	Stuck-up valve or tappet.	No compression.
	Broken valve spring	—
	Lack of oil	Poor compression.
	Worn cylinders, pistons, or rings.	Poor compression.
	Water in cylinder ..	Due to cracked cylinder or condensation in a long rising exhaust pipe.
ii. Faulty running (engine suddenly stops).	Air-lock or break in petrol pipe.	—
	Choked petrol jet.	—
	Water in petrol.	—
	Earth lead shorting to frame.	—

Symptom	Cause	Remarks
iii. Faulty running (engine runs jerkily and loses power).	One or more cylinders misfiring owing to:—	
	Faulty plug.	—
	Disconnected lead.	—
	Valve or spring broken.	May cause popping-back.
	Valve stuck up ..	Popping-back in carburettor.
	Overheating.	—
	Faulty mixture owing to:—	
	Obstructed petrol-pipe system.	Gives a weak mixture which causes popping-back in the carburettor.
	Partially choked jet	
	Water in petrol ..	
	Too much petrol, due to grit under needle valve, &c.	Black and strong-smelling exhaust.
iv. Knocking ..	Spark too far advanced for speed and throttle-opening.	Ignition knock.
	Engine too hot ..	
	Carbon deposit on piston.	Clean at first opportunity.
	Big-end loose or worn	Mechanical knock. Report at once.
	Gudgeon pin loose or worn.	
	Crankshaft bearings loose.	
	Overload.	
	Speed too low.	
v. Engine *screams* ..	Insufficient oil or blocked oil passages. If allowed to continue the piston will seize.	Shut down at once. Replenish oil supply and restart; run slowly. If this is ineffective, the engine must be taken down.
vi. Engine overheats	Spark too far retarded	—
	Mixture too rich.	—
	Mixture too weak.	—
	Bad water circulation or insufficient water.	—
	Scale and oil in water-jackets and radiator.	This can usually be removed from the *cylinder only* (under supervision) by an 8 per cent. solution of hydrochloric acid. Then connect up, and fill system with a weak solution of common soda; run for 15 minutes, and flush out with water.
	Fan belt broken or slipping.	—
	Exhaust valve not lifting; tappet out of adjustment or worn.	—

Other faults peculiar to two-stroke engines

Symptom	Cause	Remarks
vii. Four-stroking ...	Over-rich mixture	Often unavoidable at light load. Often caused by carburettor flooding slightly. A lower carburettor level can usually be given with advantage on two-strokes.
viii. Loss of power; over-heating.	Poor compression (both cylinder and crankcase).	Poor compression has far more effect in two- than four-stroke engines.
	Rings stuck in their grooves.	Rings stick very often, due to the inability of the oil to withstand the heat, which is much greater than in four-strokes.
	Carbon deposit, especially in exhaust ports	Exhaust ports and passages to silencer need cleaning about twice to every decarbonization of the whole engine.
	Incorrect magneto timing.	Two-strokes normally require more spark advance than four-stroke engines. The mixture is slower burning, due to the greater quantity of exhaust gases present.
	Speed too low.	

89. *Maintenance of petrol engines that can be undertaken by the engine driver*

1. It should be the duty of every engine driver to keep both the outside and inside of his engine clean ; also to keep all connections and joints (including valves) so tight that there is no leakage of petrol, air, oil, or water anywhere on the system.

Faults that he cannot himself put right should be reported as soon as possible to his immediate superior.

Points which should be specially attended to are given in the following paragraphs :—

2. **Carburettor and petrol system.**—
   - i. There should be no leakage at the unions.
   - ii. The petrol filter should be clean.
   - iii. The float chamber should be clean and free of water.
   - iv. All joints between carburettor, induction pipe and engine should be tight. A joint of brown paper in boiled linseed oil, a copper and asbestos washer, or a thin coat of gold size will ensure this.

3. **Ignition system.**—
   - i. All terminals should be secure.
   - ii. Magneto points should be clean and even, and should separate the right distance (·012 in.).
   - iii. The magneto distributor should be spotlessly clean.
   - iv. Sparking plug points and interiors should be free from carbon.
   - v. Sparking plug points should be set to ·025 in.
   - vi. There should be no leakage between plugs and cylinder. If tightening up does not effect tightness, a new copper and asbestos washer should be used.

4. **Water circulation system.**—
   - i. All water connections should be tight.
   - ii. Pump glands (if fitted) should not leak.
   - iii. The radiator should be clean. This can usually be effected by occasional flushing out with a hose. If oil finds its way into the radiator (usually caused by a leaky cylinder head), the radiator should be filled with soda solution and the engine run for 15 minutes, after which it should be flushed out.
   - iv. Cylinder water-jackets should be freed from scale if any has formed. (*See* Sec. **106.**)
   - v. The radiator fan belt should not slip.
   - vi. The system should be drained in frosty weather.

5. **Cylinders and pistons.**—
   - i. Cylinder heads should be cleared of carbon deposit.
   - ii. Pistons should be free of carbon both on top and underneath.
   - iii. Piston rings should be free in their grooves.
   - iv. Valve caps should fit tightly. This may necessitate a new copper and asbestos washer.

6. **Valves.**—The essential points to note are :—

i. The contact surfaces of both the valve and its seating should be smooth and free from pitting. This can usually be effected by grinding in by hand with oil and emery powder.

If there is a ridge on the valve face, or the faces of the valve and seating are badly pitted the matter should be reported. (*See* Sec. **106,** para. **9.**)

ii. Valve stems should be a good fit in their guides, otherwise air leaks are liable to occur and make starting difficult. Valve guides are often renewable, but in any case the fault should be reported.

iii. Valve springs should be strong enough to close the valves quickly and surely.

iv. Valve tappets should be adjusted when hot, as explained in Sec. **105.**

7. **Crankcase.**—All joints should be properly made with some type of jointing material. A crankcase from which oil is leaking is a sign of a badly kept engine.

The lubricating oil requires frequent making up to correct level. It should be entirely run off at least once per 250 hours of actual running and replaced with new oil.

8. **Carbon deposit.**—Carbon deposit is the cause of many faults and of unsatisfactory running. It is, therefore, the engine driver's duty *to prevent its formation* as far as possible.

Carbon deposit is formed by :—

i. Incomplete combustion.
ii. Defective or incorrectly timed ignition.
iii. Atmospheric dust.
iv. Too much oil, or unsuitable oil.

Carbon deposit causes pre-ignition, overheating, loss of power, and prevents valves from closing, thereby causing pitting. It may prevent piston rings from working freely and cause trouble with sparking plugs.

To avoid its formation the following instructions should be adhered to :—

(*a*) Never run long with a black smoky exhaust (too rich a mixture). If this occurs it should be reported and the carburettor adjusted.

(*b*) Fit a fine wire gauze shield over the carburettor air openings (to exclude dust) if an air filter is not fitted. (*See* Sec. **73.**)

(*c*) Do not continue to run the engine for a very long time with a bluish smoky exhaust. This indicates over-oiling, and may be due to too high an oil level, too high an oil pressure, worn rings or cylinder, or too thin an oil.

(*d*) Do not run the engine long with the throttle nearly closed. This tends to accumulate oil in the combustion chamber and to form a carbon deposit on the valves, plugs, and combustion chamber. The excess piston clearance (especially with aluminium pistons) due to the comparatively cool piston, aggravates the trouble.

90. *High-speed petrol-paraffin engines*

1. **High-speed paraffin engines** are very similar in construction to petrol engines. They are usually more heavily built than modern petrol engines of a given power, and run at a lower speed, say, from 350 to 1,000 r.p.m.

The service fuel used is "oil, fuel, for oil engines" (*i.e*, paraffin) with petrol for starting and warming up. Their only advantage over petrol engines is that paraffin is slightly cheaper than petrol. They are not so reliable nor long-lived under service conditions, and with little difference in fuel cost it is doubtful if the installation of this type can be justified to-day.

The main differences between these engines and purely petrol engines are :—

i. The maximum allowable compression ratio is lower because the paraffin has a lower spontaneous ignition point than petrol.

ii. They have a device for assisting evaporation of the paraffin, because the induction pipe heating of the normal petrol engine does not give a sufficiently high temperature to cause evaporation of some of the constituents of paraffin.

This device usually takes the form of an exhaust-heated jacket to the induction pipe, and is known as a vaporizer. This explains why petrol is needed to start. If the vaporizer is first heated by external means, such as a blow-lamp, these engines will start from cold on paraffin, but it naturally takes longer. An adjustment is usually provided to regulate the amount of exhaust gas passing to the vaporizer, for use under different conditions of fuel or load.

2. Pl. 69, Figs. 3 and 4, show the general arrangement of the carburettor and vaporizer used on the D.V4 Crossley engine, as used for searchlight plant. The fuel, either petrol or paraffin as required, is regulated by a separate needle valve and float chamber, and, together with air, is sucked into the vaporizer through a non-return mixing valve, *a*. Exhaust gases pass through the tubes and heat the mixture on its passage past the tubes.

PLATE

SPARKING PLUGS & CROSSLEY VAPORIZER

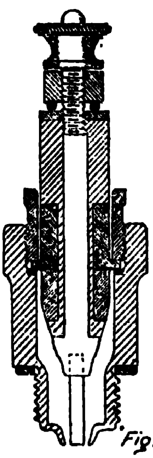


Fig 1

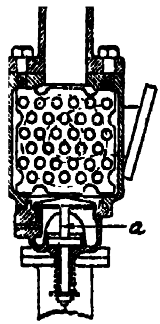


Fig. 3

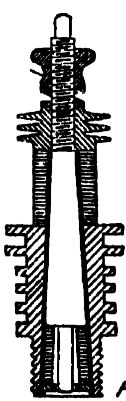


Fig 2.

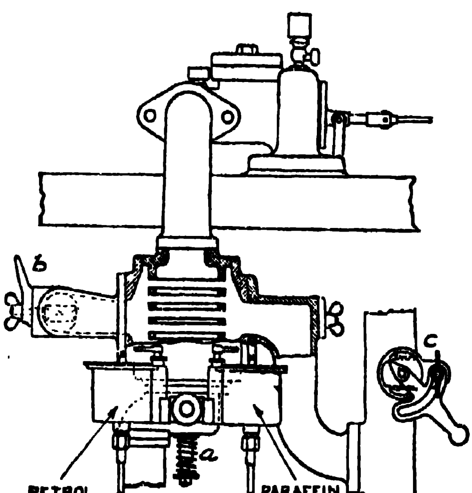


Fig. 4

3. The temperature is controlled by regulating the flow of exhaust gases through the tubes by means of two exhaust throttle levers. The smaller exhaust throttle valve, *b*, on the left-hand side of the carburettor, is to enable the exhaust to be shut off altogether, in case fuels are used requiring little or no heat for vaporizing; but for paraffin fuel it is usually left wide open. The larger exhaust throttle valve, *c*, on the exhaust pipe, regulates the flow through the tubes. For paraffin it should be about half to full open, according to the load; but for petrol it should be kept wide open.

4. **Running faults.**—

i. If the vaporizer is not hot enough when running on paraffin, the heavier fractions of the fuel do not evaporate completely and do not get sufficiently mixed with air to burn. Droplets are deposited in the cylinder, forming much carbon in the hot places, and in the cooler places, such as the cylinder walls, diluting the lubricating oil. Under these conditions in vertical engines much liquid paraffin finds its way past the piston rings into the crankcase, where further damage is done. Too cold circulating water will further aggravate the trouble; it should be as hot as possible without boiling or knocking.

ii. If the vaporizer is too hot, pre-ignition may be caused. The power output will also be lower, because the weight of a cylinder full of the overheated charge gases will be less. Water injection is used to improve matters on heavy loads.

iii. Greatest damage is done by too cold a vaporizer, and the best guides for adjustment of its heating are:—

(*a*) Pre-ignition—too hot.

(*b*) The presence of liquid paraffin in the crank-case—too cold.

(*c*) Excessive carbon deposit in combustion chamber—too cold.

With inexperienced drivers and different loads from day to day, an engine of this type cannot be expected to be long-lived.

5. These engines will normally change over to run on paraffin after five minutes full load running on petrol. It greatly assists subsequent starting if the engine is run on petrol for the last five minutes before shutting down, as this clears away any liquid paraffin in the cylinder.

6. These engines require comparatively frequent decarbonization, and the vaporizer, in particular, is very liable to soot up.

For Bibliography, see page 688.

CHAPTER XVIII

OIL ENGINES

91. *Introduction*

1. The oil engines dealt with in this chapter may now be regarded as obsolescent for military purposes, but their principles of operation should be understood if only as a stepping-stone to the study of the more modern engine dealt with in the next chapter. Moreover, there are many thousands of paraffin engines in use in various parts of the world and they have a long life.

2. Mixtures of 1 part by weight of paraffin to from 10 to 17 parts of air are explosive, and are easily ignited. Mixtures weaker or stronger in paraffin are difficult to ignite, and burn comparatively slowly. Paraffin will not vaporize completely, even at pressures considerably below atmospheric, unless it is heated up.

The usual method of vaporizing is to pump or suck a fine spray on to the heated walls of a hot bulb or vaporizer, Pl. **41**, which is a prolongation of the cylinder, and which is not water-jacketed. At starting, the hot bulb is heated up to the required temperature by a blow-lamp. When the engine is running, it is kept hot by contact with the burning charge, and the blow-lamp may be removed. The heat so given to it is not conducted away, as it is from the rest of the cylinder, by the circulating water, and a cover prevents it from being cooled too rapidly by radiation and convection.

92. *Ignition in oil engines and its control*

1. In the Hornsby-Ackroyd type of engine, shown on Pl. **70**, Fig. 1, the paraffin is introduced into the hot bulb by means of a plunger pump worked off a cam on the half-time shaft, and is forced through fine holes in a spray nipple at the side of the hot bulb, so that it meets the heated walls in a fine spray. A charge of oil is pumped up near the beginning of every suction stroke, *see* Pl. **70**, Fig. 2, and at the same time a charge of pure air is sucked into the cylinder through the inlet valve opening. As the suction stroke proceeds, some of the oil vapour passes through the narrow neck, A on Pl. **70**, Fig. 1, and mixes with the air. At outer dead centre, the proportion of oil vapour to air near the piston is much smaller than it is farther up the cylinder, and the hot

bulb itself is filled with oil vapour, practically unmixed with fresh air. It is not an explosive mixture yet, as it is too strong (*i.e.* has too great a proportion of oil and little oxygen).

On the compression stroke, the weak mixture in the cylinder is gradually forced into the compression space, of which the hot bulb is a part, and mingles with the strong mixture, until a fairly homogeneous mixture, which can be made to explode, fills the compression space near the end of the stroke. At this moment the heat of compression, combined with the heat of the hot bulb itself, is sufficient to fire that portion of the mixture *in contact with the hot bulb walls,* and an explosion is started there, which spreads to other parts of the compressed mixture until combustion is complete.

It must be clearly understood that it is only that portion of the mixture in contact with the hot walls of the vaporizer that need be explosive; once ignition has been started, the remainder of the oil vapour will be ignited and burn in the air provided by the rest of the charge, even though that portion of the charge is too weak to start an explosion under the obtaining conditions of temperature and pressure.

From this it follows that the stroke of the fuel pump can be so adjusted as to pump less fuel into the cylinder per stroke than is required to make an explosive mixture, when unevenly mixed with all the air admitted during the suction stroke, and yet the engine will continue to function, though with reduced power. This phenomenon is taken advantage of in engines when it is desired to obtain very even running with no *cut-out* strokes.

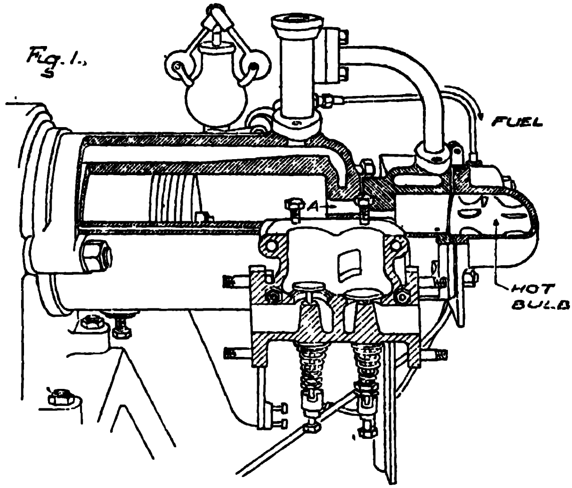
2. Suppose that the engine is working at full load, and that ignition is occurring regularly at the correct moment; the vaporizer will settle down to a uniform temperature at which it loses heat at the same rate as it receives it from the explosions. If the engine load is now reduced, the vaporizer will get cooler owing to the weaker explosions, and the mixture next to its walls will remain longer in contact with it before ignition temperature is reached; therefore, ignition will occur later in the stroke. Not only so, but as the same quantity of air is compressed every stroke, and as the power is varied by weakening the mixture, and a weaker mixture burns slower than the true explosive mixture, complete combustion of the charge may not have been obtained by the end of the stroke, with the result that a lower maximum pressure will occur inside the cylinder at inner dead centre, with a consequent lower mean pressure throughout the stroke.

A thick bluish smoke emitted from the exhaust pipe is always the sign of a cold vaporizer. If the load on an engine is reduced appreciably, the heat of the feeble explosions may not be sufficient to keep the vaporizer sufficiently warm,

PLATE 70.

HORNSBY-ACKROYD ENGINE.

SECTION OF CYLINDER AND VALVE BOX, WITH VALVE-TIMING CHART.



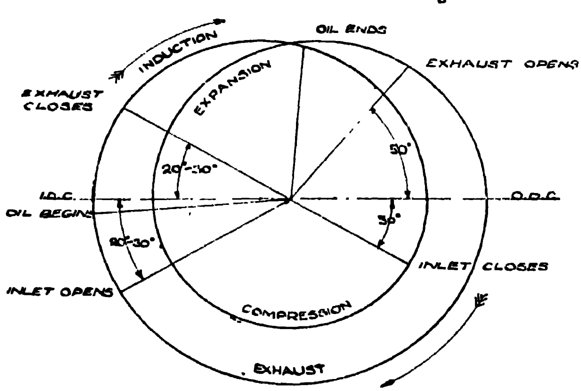
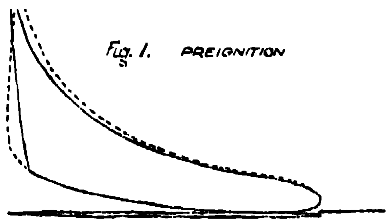


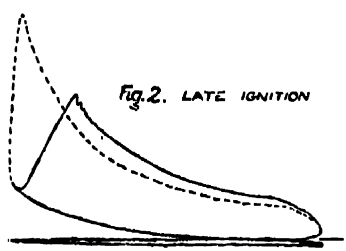
Fig. 2.

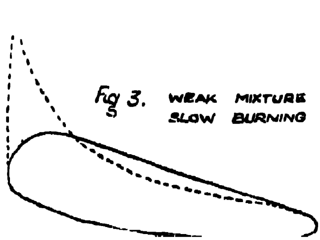
PLATE 71.

FAULTS ON ENGINES AS SHOWN BY INDICATOR DIAGRAMS.

THE NORMAL DIAGRAM IS SHOWN DOTTED IN EACH CASE







and it will then be necessary to keep the blow-lamp under it whilst running light.

Pl. **71**, Fig. 3, shows a diagram obtained with a weak mixture, and shows loss of area (and, therefore, of power).

If the bulb could be made hotter, ignition would be produced earlier, in time to allow complete combustion of the charge by *inner* dead centre.

3. Now consider the case in which the vaporizer is too hot. With the heat given by compression remaining the same as before, that portion of the charge in contact with the vaporizer walls will reach ignition temperature earlier in the compression stroke, with the result that ignition will be too early. Pl. **71**, Fig. 1, shows a diagram from an engine where this has occurred. Not only is power lost, as shown by the diminished area of the diagram, but a metallic knock or a thump is heard as the piston, driven by the flywheel, meets the explosion pressure before it has completed its stroke. If this knocking is allowed to continue, the bearings, &c. of the engine may be damaged.

4. The principles of the formation of the explosive charge are similar in engines by different makers, but differ in detail. One type of Tangye oil engine, Pl. **72**, Fig. 1, has an automatic inlet valve, *a*, and a gravity-fed fuel supply, which is led to a small hole, *b*, above the inlet valve seating, through a pipe, *c*, provided with a graduated cock, *d*. In this engine the oil is sucked into the vaporizer by the action of the piston during the suction stroke, the cock, *d*, being set to give the correct amount of fuel.

5. **Timing the ignition.**—From the above it will be clear that some method of timing the ignition is necessary.

The two most usual methods employed are :—

i. Regulating the heat of the hot bulb or ignition tube (*see* para. 7), reducing it as the load increases and *vice versa*.

ii. Reducing the heat of both charge and vaporizer by spraying water into the charge.

6. **Regulation with hot bulb engines.**—The vaporizer of the Hornsby engine is joined to the cylinder by the neck, A on Pl. **70**, Fig. 1, which is water-jacketed. The flow of water round the neck is regulated by a valve, and hence its temperature can be varied to suit the load and to obtain the correct point of ignition. In practice the valve is opened to the point at which knocking (pre-ignition) is found to cease. Removal of the vaporizer cover, Pl. **41**, will also tend to cool the vaporizer.

At very light loads the vaporizer may become too cold either to cause ignition or to vaporize the oil properly. In such cases the lamp must be placed underneath it.

7. **Regulation in engines provided with a hot tube.**—In the Tangye engine, Pl. **72**, Fig. 1, oil is sucked into the vaporizer, but a hot tube, *t* on Pl. **72**, Fig. 2, made of nickel steel, is used to effect ignition. The temperature of the tube is maintained by surrounding it with hot gas admitted through a regulating valve from the vaporizer.

The point at which ignition occurs can be made earlier or later in the stroke by making the hot tube, *t*, hotter or cooler, by means of the regulating valve, Pl. **72**, Fig. 2, which allows more or less of the very hot products of combustion access to the outside of the hot tube. As in the case of the Hornsby engine, when the load increases, the vaporizer tends to become hotter, and the now stronger mixture tends to ignite sooner and to complete explosion quicker; the temperature of the hot tube is therefore reduced in order to correct the point of ignition.

8. **Water injection.**—In many of the older types of low-compression oil engine, provision is made for injecting a small quantity of water into the combustion space. The vaporization of the water restricts the internal temperature, and this permits a higher compression pressure to be used without pre-ignition than would otherwise be possible and enables the rating of an engine to be increased.

In the Tangye engine (Pl. **72**, Fig. 1) sufficient water is admitted to remove the heavy bumping or knocking sound from the explosions. The amount of water required to do this, naturally increases with increased load.

Water injection is used in the Crossley petrol-paraffin engine when running on heavy loads with paraffin as fuel.

Although primarily introduced to improve the working of engines on heavy load, water injections can clearly be used to regulate the time of ignition at other loads.

The introduction of water, however, has objectionable features in that it interferes somewhat with cylinder lubrication and may also lead to internal corrosion.

In modern types of engine, water injection is seldom employed.

9. **Altering the compression.**—Some method of regulating the compression pressure is useful, as some grades of oil detonate sooner than others. This can be done by:—

i. Altering the position of the piston in the cylinder by inserting metal plates of the required thickness between the connecting rod and the crank pin brasses, Pl. **72**, Fig. 4.

PLATE 72.

7 B.H.P. TANGYE OIL ENGINE DETAILS.

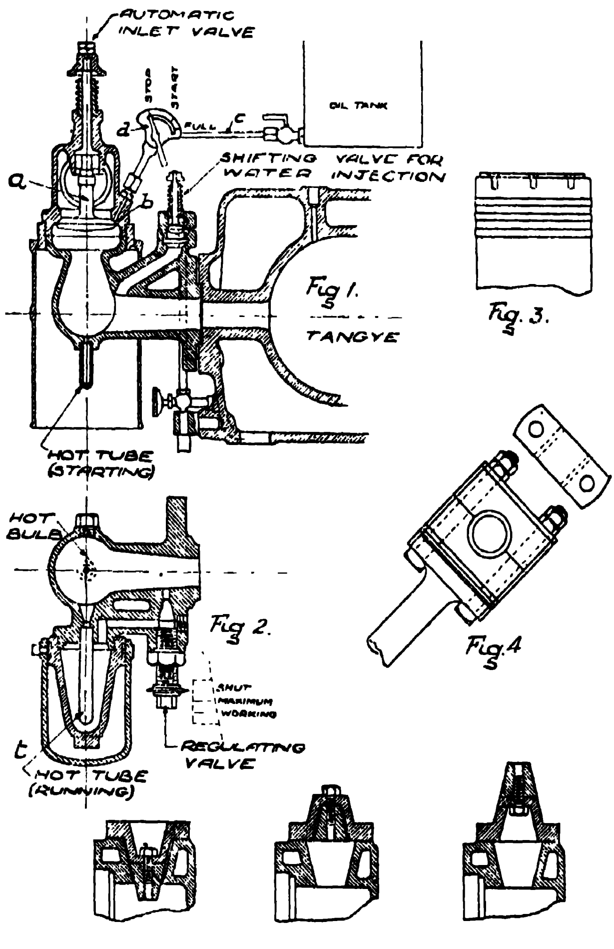


Fig 1. Fig 2. Fig. 3. Fig. 4. Fig. 5.

ii. By altering the compression space with conical caps, Pl. **72**, Fig. 5.

iii. By replacing the hot bulb by one of greater or smaller volume.

iv. By securing a plate with set screws to the end of the piston, Pl. **72**, Fig. 3.

Method (iv) can be adopted in the case of engines not fitted by the makers with other devices for regulating compression pressure, but should only be used for small engines. In order to maintain the designed maximum compression, pressure, when engines are installed at high altitudes, the compression ratio may be increased to compensate for the rarefication of the atmosphere. This may be done by grinding a little off the face of the cylinder head flange.

93. *Running and care of oil engines*

1. The following instructions are of a general nature, and apply to all makes of horizontal oil engine. As it is not feasible to include *the details* of all types, reference should also be made to the engine maker's instructions.

2. **Before starting.**—See that the water-jacket and all cooling tanks are filled with water, the level of the water being at least 2 inches above the top of the flow pipe from the engine.

See that the engine is in a fit condition to run, *i.e.* no nuts or other fastenings have been removed or have become loose.

See that all lubricators are filled and that they will work; oil where necessary with a can. See that the fuel tank is full.

Make sure that it is known how to stop the engine.

3. **Working the lamp.**—Fill the container *not quite* three-quarters full with paraffin, and replace the filler cap, Pl. **56**, Fig. 3. Open the air valve, *a*. Fill the cup, *b*, with paraffin, place some rag in it to act as a wick, and light it. When the oil in the cup is nearly consumed, and not before, close the air valve, *a*, give a few strokes with the pump, *c*, and open the regulating valve (if fitted). The gases now escaping through the nipple, *d*, can be lit. The flame should now be increased by further strokes of the pump, *c*. Should liquid paraffin issue from the nipple (indicated by a large yellow flame), the lamp is too cold. Reopen the air valve, *a*, and reheat.

Should the flame, notwithstanding pumping, burn faintly, see :—

i. That the nipple is cleared by means of the pricker needle (and with nothing else).

ii. That there is sufficient paraffin in the container.

iii. That the filler cap does not leak.

iv. That the pump leather is sound.

To extinguish the flame, open the air valve and leave it open. On no account should the lamp be allowed to burn itself out, or the nipple will be choked with carbon.

4. **Starting.**—

i. Place the burning lamp under the engine vaporizer (which should have its cover in position), and leave it there for 15 to 20 minutes, according to the size of the engine. The vaporizer will then probably be sufficiently hot to start. Test for vapour by opening the indicator cock or let a drip of paraffin fall on the vaporizer, which, if hot enough, will dry the paraffin in 3 to 5 seconds.

ii. Now bring the half-compression cam into action. Turn on the fuel tap and, if the engine has a fuel pump, give it two strokes by hand.

iii. Pull the flywheel backwards until the compression reverses its motion ; then pull it vigorously in the forward direction. After two revolutions the engine should start. **Never stand on flywheel spokes.**

iv. Put the half-compression cam out of action.

v. Gradually put the engine on load and remove the lamp.

vi. Adjust the governor to give the required engine speed.

Failure to start may be due to :—

i. Vaporizer too cold. This is indicated by thick bluish smoke from the exhaust.

ii. Insufficient fuel supply, owing to choked spray holes or faulty pump.

5. **Running (oiling).**—As soon as the engine commences to run under its own power, examine the lubrication system in the following order :—

i. Main crankshaft bearings, to ascertain if ring lubricators are working.

ii. All sight-feed lubricators, and adjust the number of drops per minute in accordance with the maker's instructions. The piston should be kept lightly oiled.

iii. All oil-holes fed by an oil can.

6. **Running (circulation).**—Keep the regulating cock on the cooling system closed until the top of the water-jacket becomes uncomfortably hot to the back of the hand. Then open the regulating cock so that water can circulate through the jacket at a rate sufficient to maintain this temperature. It is important that engines should not be run too cold, or the fuel consumption will go up and the speed will fall.

Cooling tanks not provided with a ball-cock must be *made up* occasionally to keep the water level two inches above the flow pipe.

7. **Running (knocking).**—Knocking is of two kinds, viz. :—

i. That due to worn or loose parts. Local orders must be concise as to action to be taken when such mechanical knock is noticed.

ii. That due to pre-ignition. This is due to a vaporizer or ignition tube becoming too hot, usually when the engine is heavily loaded or internally dirty. It should be remedied as soon as possible by one or more of the following devices, according to the type of engine :—

(*a*) Remove the vaporizer cover (Hornsby, Blackstone).
(*b*) Increase the water circulation round the *water neck* (Hornsby).
(*c*) Adjust the heat of the tube (Tangye).
(*d*) Inject water into the cylinder (Tangye, Blackstone).
(*e*) Decarbonization.

Care must be taken, however, not to over-cool, or the engine will stop.

8. **Running (light load).**—When the engine is running light, the vaporizer will tend to get too cold. This is indicated by a smoky exhaust, and, if allowed to continue, the engine may stop. To avoid this, steps must be taken to keep the vaporizer hot (*e.g.* replace cover, turn off water injection, &c.), and it may be necessary to replace the lighted lamp under the vaporizer.

9. **Hot bearings.**—During running, the big-end and main crankshaft bearings should be occasionally felt with the hand to ascertain if overheating is taking place. At the least sign of overheating, give more oil ; if this fails to remedy matters, take off the load ; then stop it and investigate.

10. **Seizing.**—Should an overheated bearing or piston not be detected, it will soon seize. Warning is generally given by a characteristic groaning noise. The load should be immediately taken off, and the engine, if possible, kept running very slowly, while the affected part is flooded with oil. Should it still continue, the engine must be stopped, the bearing allowed to cool (not with water), and the cause then investigated.

The brasses must not be loosened until cool, or they will distort out of shape.

Overheating of brasses is due to one of the following causes :—

i. Insufficient lubrication.
ii. Too tight on the shaft.
iii. Shaft or bearings out of line.
iv. Inaccurate fitting.
v. Presence of dirt or grit in oil or oil grooves.

A piston on the point of seizing should be turned to inner dead centre, and allowed to cool slowly. Soaking in paraffin may be necessary before it can be removed.

11. **Stopping.**—

i. Take the load off the engine.
ii. Cut off the fuel supply.
iii. Turn off the lubricating oil in the sight-feeds and remove trimmings from siphon lubricators.
iv. Turn the engine until piston skirt edge is flush with that of the liner on the firing stroke (to exclude dirt). Wipe down the engine.
v. Do not turn off the cooling water circulation for at least ten minutes after a hot engine has stopped.
vi. If danger by freezing is anticipated, the water jackets and pipes (not necessarily the tanks) must be completely drained.

12. **Faults.**—The following table shows some normal running faults met with in oil engines and how they are dealt with :—

Symptom	Cause	Remedy	Remarks
Engine fails to start, or stops	Vaporizer too cold	Reheat vaporizer	Usually accompanied by bluish smoke in the exhaust.
	Fuel supply cut off owing to :—		
	Faulty pump	Decide after examination	
	Air-lock in pipe		
	Choked spray	Clear with pricker provided	Spray holes must on no account be enlarged.
Engine fails to develop its power	Vaporizer too hot	Regulate point of ignition by water injection or other means	Accompanied by knocking.
	Vaporizer too cold	Regulate heat of vaporizer and, if necessary, replace lamp	Usually accompanied by bluish smoke in the exhaust.

Symptom	Cause	Remedy	Remarks
Engine fails to develop its power —*continued*	Loss of compression due to :—		
	Dirty valves	Clean	——
	Pitted or grooved valves	Grind-in	——
	Piston rings stuck up	Draw piston, and clean by soaking in paraffin	Do not remove rings unless absolutely necessary.
	Lack of oil ..	Lubricate	——
	Incorrect valve timing due to :—		
	Too much tappet clearance	Adjust in accordance with maker's timing	——
	Half - time gears meshing incorrectly	Re-mesh according to maker's marks on gear wheels	——
	Weak or broken valve springs	Renew springs	——
	Partial stoppage in fuel system	*See* above	——
Governor fails to act, and engine runs away	Governor gear sticking	(i) Immediately stop engine by cutting off fuel supply	If speed is allowed to increase unduly, the flywheel may burst.
		(ii) Thoroughly clean and lubricate	——
	Weak vapour-valve spring (Blackstone)	Renew spring	——.
Knocking due to pre - ignition at comparatively light loads, getting gradually worse over long periods	Carbon deposit on piston, cylinder, and vaporizer	Draw piston and decarbonize engine	Points of carbon become red-hot, and compression increases.
	Engine overheated, due to deposit in water-jacket or circulating pipes	Clean, under supervision of mechanist, by drawing liner and chipping, or by 8 per cent. solution of hydrochloric acid	If acid is used, a final rinsing in soda solution to eliminate traces of acid is necessary.
Blowing through between cylinder and vaporizer	Joint washer damaged	Replace ..	A new joint is required *each time* vaporizer is replaced after removal.

Symptom	Cause	Remedy	Remarks
Knocking of bearings	Loose bearings..	Take up bearings	Normally fitters' work.
Overheating of bearings	Insufficient oil..	Obvious ..	Oilways may be stopped up.
	Too tight ..	Loosen ..	Fitters' work.
	Out of line ..	Report	Fitters' work.
Groaning ..	Piston about to seize through lack of oil	Take load off engine. Run slowly. Flood with oil	Stop engine as a last resort.
	Any bearing about to seize	Take load off engine. Run slowly. Flood with oil	Stop engine as a last resort.

13. **Inspections.**—Apart from the continual vigilance for faults to be exercised by the engine driver during the time he is on duty, it is advisable to carry out minor inspections, in order that incipient faults may be checked and remedied, at definite intervals—once a month for continuous running, and never less often than once a year.

The points to be attended to are :—

i. Draw piston ; clean carbon from piston head, piston ring grooves and cylinder ; see that rings are working freely.
ii. Draw all valves ; clean off carbon, and grind in where necessary. If grooved, they should be trued in a lathe.
iii. Adjust all valve tappets to maker's setting.
iv. Clean spray holes with pricker provided (this should also be done at intervals of 15 hours' running).
v. Remove vaporizer ; clean and replace it, making a new jointing washer.
vi. Empty all oil troughs (siphon or ring system) ; clean out and fill with fresh oil.
vii. Examine fuel pumps and pipes for leakage, and tighten glands where necessary.
viii. Examine circulating system for scale, and remove if necessary ; stop any leaks.
ix. Examine exhaust system for excessive accumulations of soot, and drain the silencer.

94. *Mechanical aids for oil-engine starting.*

1. It is convenient to have compressed-air starting appliances installed for all oil engines of 20 H.P. and over. When so fitted, engines can be quickly and surely started by one man.

2. Dealing first with single cylinder engines, a typical arrangement is shown in Pl. **73** in which the engine cylinder acts as the compressor; air so compressed is stored in a receiver until required for readmission to the cylinder for starting. It comprises :—

i. A receiver, Pl. **73**, Fig. 1, into which air can be compressed on the compression stroke. This receiver is fitted with a pressure gauge, stop-valve and drain cock.

ii. A starting and charging valve-box.

In the starting and charging valve-box, Pl. **73**, Fig. 2, are two valves, G and H, which communicate directly with the cylinder and the receiver. A starting lever, E, pivoted at F, actuates valves G and H. If moved in the direction shown by the arrow, the valve G will first be lifted against its spring by the arm K, and then the valve H will be lifted off its seating by the arm L, both valves being then held off their seating.

3. To charge the air receiver, the fuel supply is first completely cut off, the engine running on by flywheel momentum and valve K (Pl. **73**, Fig. 1) is opened. The starting lever is moved until it lifts valve G only; valve H is still on its seating, and as soon as the pressure in the cylinder is greater than that in the receiver, valve H will be lifted, and air will pass into the receiver. When the engine cylinder pressure falls below receiver pressure, valve H will close, and act as a non-return valve in preventing compressed air from leaking back into the cylinder.

Charging should normally be carried out only when the engine is well heated up.

It will then be necessary to close valve K, run the flywheel up to speed again, then open valve K and repeat the process.

4. The method outlined in para. 3 is somewhat tedious, and in the case of low compression engines it is common practice to charge the receiver while the engine is running on light load. This means filling the receiver with exhaust gases, which might include some oil vapour from unburnt charges.

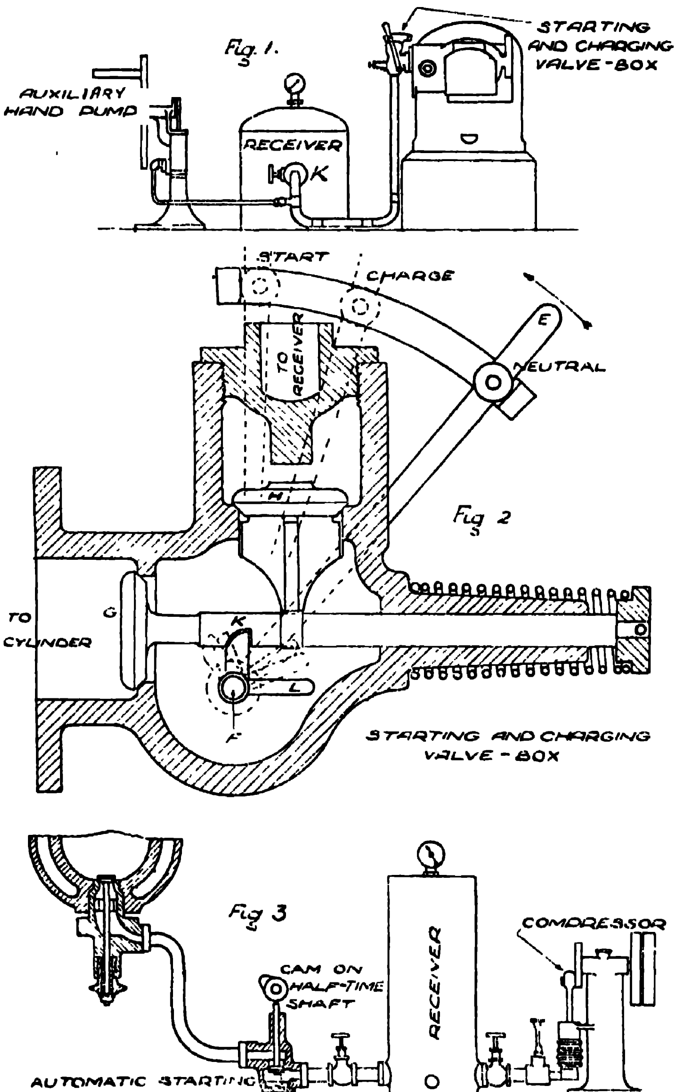
This practice must be absolutely forbidden with high compression engines. *See* Sec. **96**, paras. 4 and 5.

5. In multi-cylinder engines it is usual to cut off the fuel from one cylinder and use it as an air compressor driven by the other cylinders.

6. **To start the engine,** the vaporizer must first be heated as usual. The engine is put on the power stroke, with piston just after inner dead centre. The by-pass (fuel valve) is closed, and the valve K (Pl. **73**, Fig. 1) between the cylinder

PLATE 73.

TYPICAL AIR-STARTING ARRANGEMENTS.



and the receiver is opened. The engine need not generally be put on half-compression.

The starting lever is pushed to the *start* position, thereby lifting valve H from its seat, as well as valve G, and allowing compressed air at about 100 lb. pressure to enter the cylinder from the receiver.

The piston is driven forward, and when it gets to about three-quarters stroke, the starting lever is brought to the *run* position, thus closing the passage between the cylinder and receiver. This is done to avoid air escaping during the exhaust stroke. The attendant watches the engine crank, and brings the starting lever to *start* at the beginning of the next power stroke, and the process is repeated until the flywheel has been given sufficient momentum to start the engine.

Valve K (Pl. **73**, Fig. 1) is then shut down. A pin is generally fitted in a quadrant to determine the charge position.

The receiver can be recharged before stopping. In some cases an auxiliary air compressor is supplied to fill the receiver should it lose its pressure.

7. A certain amount of care is required in working receivers. They are made like a boiler, and should be similarly treated, *i.e.* fitted with a safety valve and pressure gauge, painted or tarred to arrest corrosion. They should be supported on some damp-proof material with all parts exposed for examination. A drain-plug or cock should be provided, and frequently used. Being constructed for certain definite working pressures, these pressures should not be exceeded.

Receivers should be tested yearly, as laid down in Regulations for Engineer Services, Part II.

CHAPTER XIX

HEAVY-OIL ENGINES

95. *Introduction*

1. "Heavy-oil engines" is a loose general term often used to cover all engines which work with "heavy" oils.

To ensure the *complete combustion* of such oils in a cylinder, better atomization of the fuel and higher temperatures than are obtained in the paraffin oil engine must be employed.

In order to obtain higher temperatures in the cylinder, it is necessary to work with higher compression pressures.

2. In the paraffin oil engine, if the mixture is compressed beyond 60 to 80 lb. per square in., the heat of compression will cause pre-ignition. The spontaneous ignition point of the heavier oil fuels being much the same as that of paraffin, it is not feasible to raise compression pressures in heavy-oil engines beyond this point if the *mixture* is compressed.

3. In all heavy-oil engines, pure air only is, therefore, drawn into the cylinder on the suction stroke and compressed. Near the end of the compression stroke a charge of heavy oil is introduced into the cylinder in a very finely-divided spray, and is quickly vaporized and ignited by the high temperature of compression, in some cases aided by a hot bulb.

Engines of this type not only use a cheap fuel, but, having a high compression ratio and, therefore, a high thermal efficiency, they also have a low fuel consumption.

The service fuels used for these engines are, *Oil, fuel, for heavy-oil engines*, and *gas oil.*

4. **Fuel oil filtering.**—Heavy fuel oil must always be strained before use, otherwise the fine orifices of atomizers will quickly become choked. A strainer is invariably incorporated in the expense oil tank and one or two other strainers may be inserted in the fuel oil circuit.

5. **Fuel oil heating.**—The object of this is to make the oil more fluid, thus enabling it to flow more easily through the pumps, pipes and passages into the atomizers. It may only be necessary in cold weather. The heat of the exhaust is generally used for this purpose.

The degree of heating can be regulated by varying the distance of the heater from the exhaust pipe. The distance should never be such as to cause the oil to give off vapour; otherwise an air-lock would be caused in the pipes and pump,

and prevent their functioning properly. A small cock is fixed in the top of the heater, and, by opening this, an indication can be obtained as to whether vapour is being produced.

Generally, between 80° and 100° F. has been found a suitable temperature, but on no account should it exceed 120° F.

6. Heavy-oil engines are sub-divided into the following main types :—

i. Semi-Diesel engines.
ii. Diesel engines.

96. *Semi-Diesel engines*

1. Semi-Diesel engines will be dealt with first, but they are now practically obsolescent except in small sizes (say) up to 25 B.H.P.

The fuel used is gas oil or any other heavy oil of S.G. not greater than about 0·9.

The compression pressure varies between 150 and 300 lb. per square in. in different engines, and the maximum explosion pressure varies between 350 and 550 lb. per square in.

Owing to the high pressures, safety valves are often fitted in the combustion chambers, to guard against abnormal pressures, which may occur in the event of bad pre-ignition. Such abnormal pressures may also occur during starting, but are not common.

The operation of semi-Diesels is similar to that of the oil engines (paraffin only), with these exceptions :—

i. The method of atomizing the fuel.
ii. The necessity in certain cases for pre-heating the viscous fuel to allow it to circulate freely.
iii. The time of introduction of the fuel.

2. Pl. **74**, Fig. 1, shows, in section, a typical semi-Diesel, working on the *four-stroke cycle*, and Pl. **74**, Fig. 4, shows the valve and fuel injection diagram (for full load). Pl. **74**, Fig. 3, shows a typical indicator diagram.

3. **Atomizing the fuel.**—Pl. **74**, Fig. 2, shows a typical atomizer, pulverizer or *spraymaker*. A quick down-stroke of the fuel-pump plunger forces oil along a pipe to the chamber, *a*. The fuel valve, *b*, is forced back from its seating, *c*, by the oil pressure against the strong spring, *e*. The fine grooves in *d*, through which the oil is now forced, are spiral at the lower end, and the spinning motion thereby imparted to the oil causes it to spread out by centrifugal force into a fine mist as it issues from the annular space between the valve, *b*, and its seating, *c*, into the hot bulb.

The object of the pipe, *g*, is to allow any oil which leaks past between the valve, *b*, and the body of the atomizer to escape freely, for if it were unable to do so it would prevent the valve, *b*, from lifting.

The fine atomization, which is so essential to the complete and rapid combustion of the fuel, necessitates a very high mechanical pressure (1,000 lb./sq. in. or more) on the fuel during the period of injection, *i.e.* during the down-stroke of the fuel-pump plunger.

It is, therefore, important that there shall be no leaks in the system, viz., the pump stuffing box and fuel pipe unions.

The atomizer must be treated with great care, and, if dissembled, the parts must be carefully cleaned with paraffin, and on no account dropped on the floor. When reassembling, care must be taken not to disturb the adjustment.

Some atomizers have a spray plate similar to that on the spray box of the Hornsby-Ackroyd. The holes, which are very small, are liable to become choked.

The atomizer shown on Pl. **74**, Fig. 2, is water-cooled, to prevent it being damaged by the heat of the hot bulb. Care must be taken to ensure that there is water in the jacket, *f*, while the hot bulb is being heated for starting.

Great care must be taken not to disturb the adjustment of the atomizer.

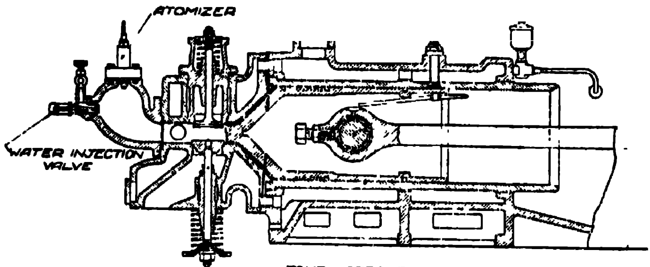
4. **Compressed-air starting** is usual for these engines over 10 H.P. In some semi-Diesels, the air starting arrangements are as described in Sec. **94**, paras. 2 and 3. Charging the receiver is effected by running the engine up to speed, then shutting off the fuel supply and bringing the valve box lever into the charging position. This ensures that none of the fuel can be injected into the high-pressure air in the receiver, and avoids any dangerously high pressures which might be caused by an explosion therein.

Starting is effected as described in Sec. **94**, para. 4, except that a cam on the half-time shaft actuates the valve between the receiver and the cylinder, and thus avoids the necessity of moving the starting lever backwards and forwards at starting.

5. Another arrangement of compressed-air starting is illustrated in Pl. **73**, Fig. 3, which shows a separate compressor for charging. The separate compressor need not be used if some arrangement for holding open the air starting valve in the cylinder is available. On the compression stroke, the movable cam-operated valve will then open automatically, the cam being put out of action.

PLATE 74.

TANGYE ENGINE DETAILS AND TIMING CHARTS



FOUR - STROKE SEMI - DIESEL

Fig 2
ATOMIZER

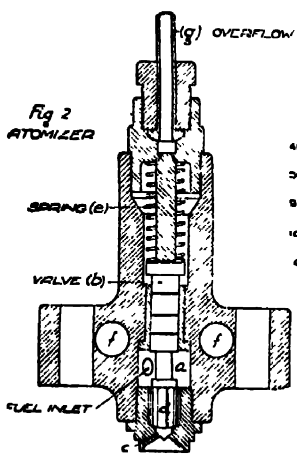
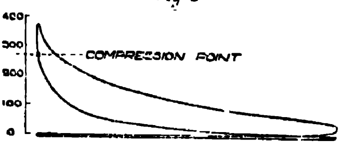


Fig 3



TYPICAL SEMI-DIESEL DIAGRAM

FOUR-STROKE SEMI-DIESEL

TWO-STROKE SEMI-DIESEL

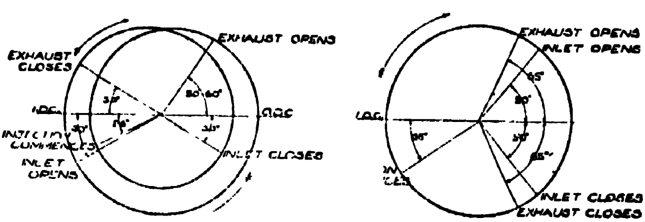
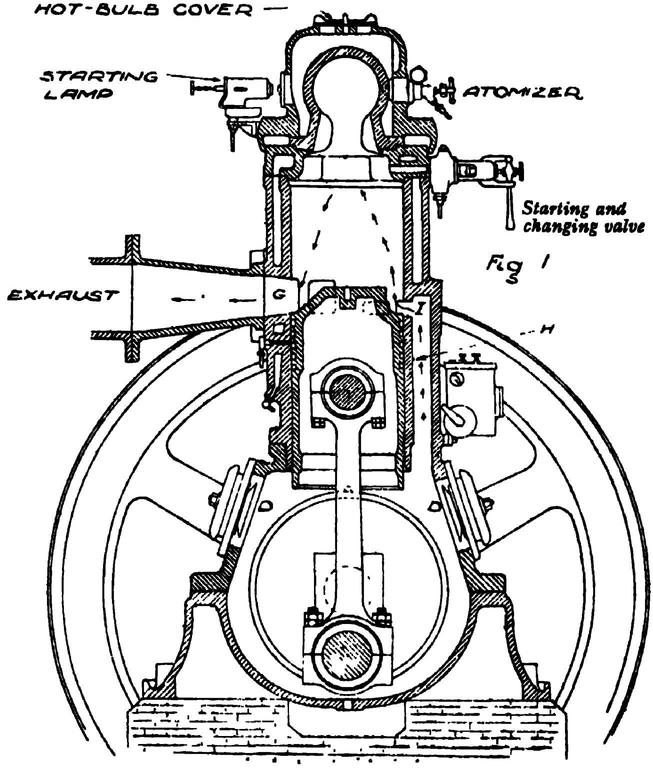
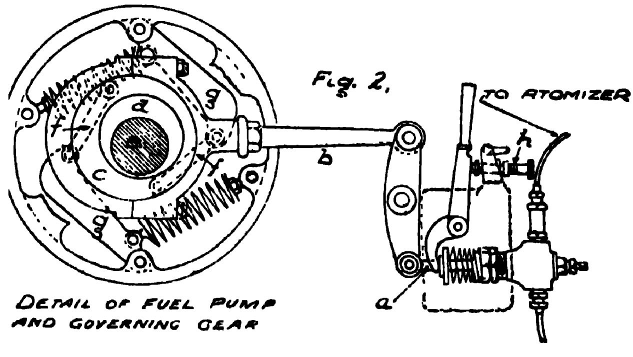


Fig 5

PLATE 75.

VERTICAL TWO-STROKE SEMI-DIESEL ENGINE.





DETAIL OF FUEL PUMP AND GOVERNING GEAR

6. The **two-stroke semi-Diesel,** usually vertical, is quite a good type of engine for stationary and semi-portable military purposes.

i. It is lighter for a given power than the horizontal four-stroke type.
ii. Having no valves in the cylinder head, and few adjustments, it is fairly simple to operate and maintain.
iii. It is more economical than the four-stroke paraffin engine to which the two-stroke principle cannot be economically applied, but it is not so economical as two-stroke or four-stroke Diesels.

7. Pl. **75,** Fig. 1, shows a typical two-stroke semi-Diesel engine.

Pl. **74,** Fig. 5, shows a typical port-timing diagram.

Air only is compressed in the crankcase, *which must therefore be kept airtight.* The fuel injection is similar to that of a four-stroke semi-Diesel.

The exhaust port is uncovered for a comparatively small portion of the working stroke. If the exhaust gases are to escape without undue back pressure *the silencer must be very near the cylinder.*

8. **Compressed-air starting** is effected as described in paras. 4 and 5 (except that the valve between the receiver and cylinder is actuated by a cam on the crankshaft).

9. **Reversing.**—Two-stroke semi-Diesels can be made to run in a reverse direction by altering the time of fuel injection. This will be obvious on looking at the port and fuel timing diagram in Pl. **74,** Fig. 5. This will involve moving the cam or eccentric device which operates the pump through an angle of, say, 30 degrees relative to its shaft. Such adjustment may be provided by the makers.

10. **Faults in semi-Diesel engines.**—The semi-Diesel is prone in general to the faults which have already been dealt with in Sec. **93** for oil engines.

i. *Faults common in semi-Diesels.*—The greatest difficulty in semi-Diesels is to ensure always complete combustion when the engine is on varying load, such as electric lighting, and to avoid pre-ignition. This is because of the variation in temperature of the hot bulb. The temperature of the hot bulb can be increased or decreased by the application or removal of the blow-lamp, or by adjustment of the water snifting device. In this connection errors of judgment on the part of the driver will lead to dirty exhaust or pre-ignition, both of which will be harmful to the engine, and may cause excessive fuel consumption. Below about one-third of full load it is generally necessary to use the blow-lamp.

ii. *Faults peculiar to two-stroke semi-Diesels.*—

(*a*) The atomizer nozzle is somewhat more frequently choked with carbon due to higher local temperature. This fault may become very frequent if, on shutting down, the engine is not allowed to cool gradually. The water circulation should always remain in action for some minutes after the engine has stopped.

(*b*) Like all two-stroke engines, the exhaust ports become choked up with carbon. This has a remarkably bad effect on the power output. Ports should be cleaned about twice as often as the piston top. The exhaust pipe layout should give as much freedom from back pressure as possible. There should be an expansion chamber close to the port.

(*c*) Excessive lubricating oil consumption as compared with four-stroke semi-Diesels of the same power is difficult to avoid without risk of seizure.

97. *Diesel engines (air-injection), general principles*

1. The true Diesel engine may work either on the four- or two-stroke principle.

Pure air only is compressed to from 450 to 500 lb./sq. in. Near the top of the stroke, fuel is injected through a pulverizer by a blast of air at a pressure of from 600 to 900 lb./sq. in., depending upon the load and the type of fuel used.

Compressed air is provided by a compressor forming an integral part of the engine, air receivers (or bottles) being located between the compressor and the pulverizer.

2. The true Diesel cycle is shown in the typical indicator diagram, Pl. **76**, Fig. 2, and timing diagram, Pl. **76**, Fig. 1.

It will be noted that the explosion pressure does not rise much above the maximum compression pressure, and that the indicator diagram has a flat top under load. This is explained by the gradual burning of the oil as it is injected during an appreciable portion of the stroke. In practice, however, there is a slight rise of pressure during combustion.

The true Diesel cycle is defined as one in which combustion takes place at constant pressure (and varying volume as the piston recedes), as opposed to the Otto cycle, on which oil engines work, in which combustion takes place at constant volume (*i.e.* almost instantaneously at the inner dead centre).

3. Pl. **77** shows the general layout of an air-injection Diesel engine installation and is self-explanatory. The cylinders are usually vertical.

PLATE 76.

TIMING AND INDICATOR DIAGRAMS
AIR INJECTION DIESEL ENGINE.

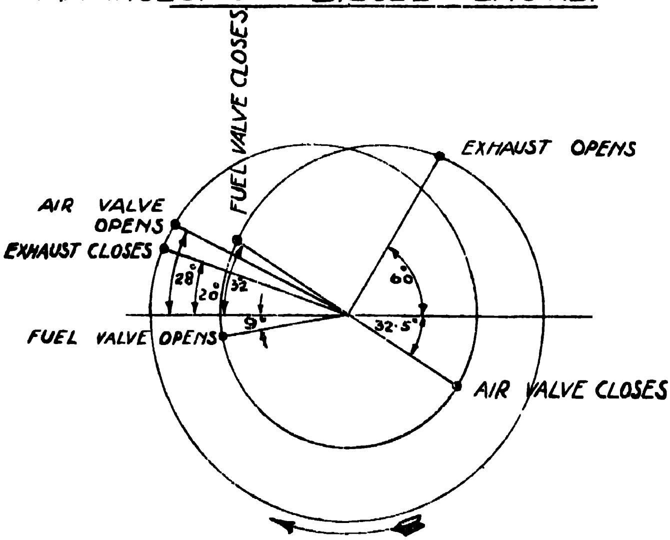


Fig 1

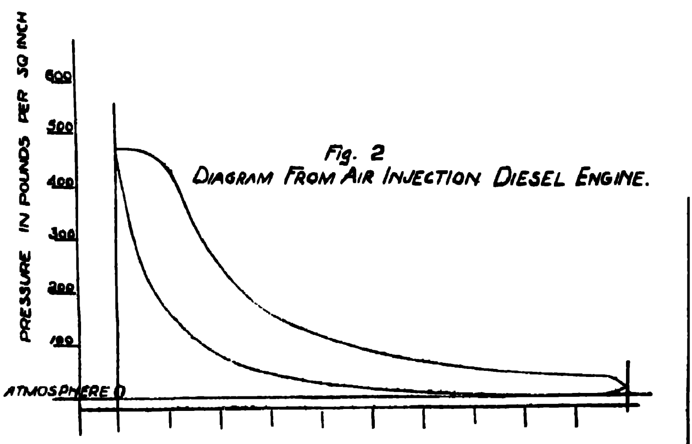


Fig. 2
DIAGRAM FROM AIR INJECTION DIESEL ENGINE.

PLATE 77.

LAYOUT OF AN AIR-INJECTION DIESEL OIL ENGINE

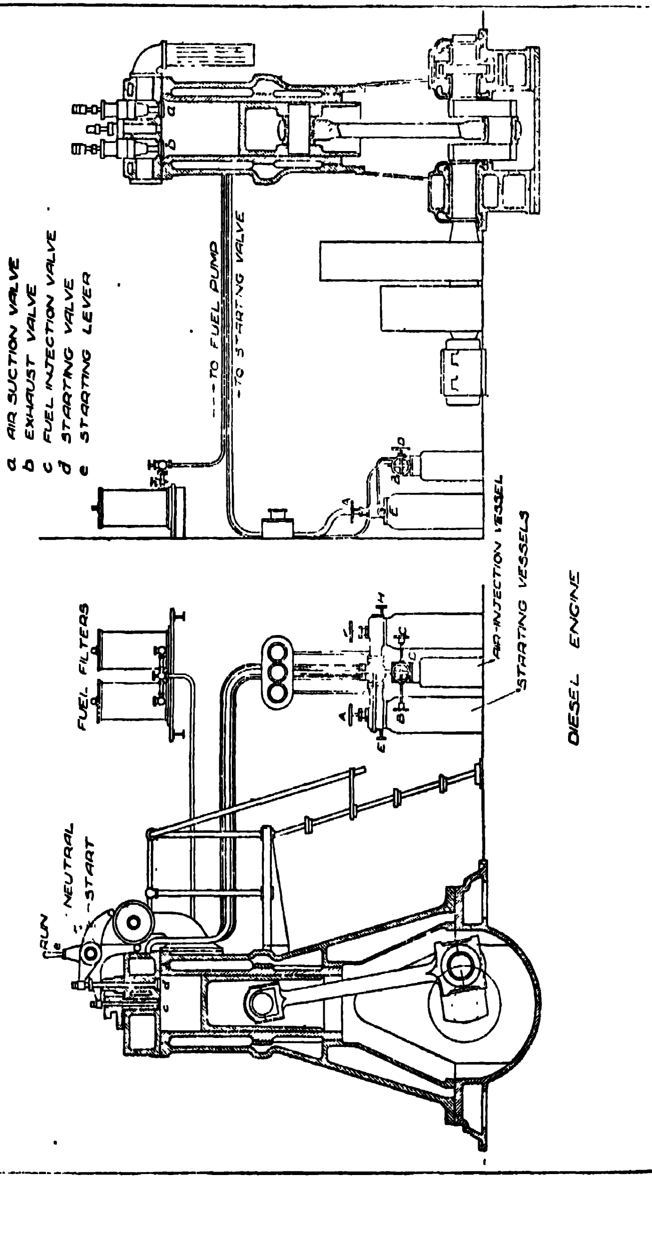
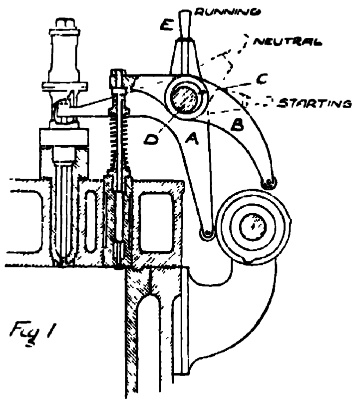
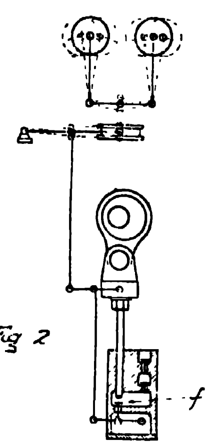


PLATE 78.

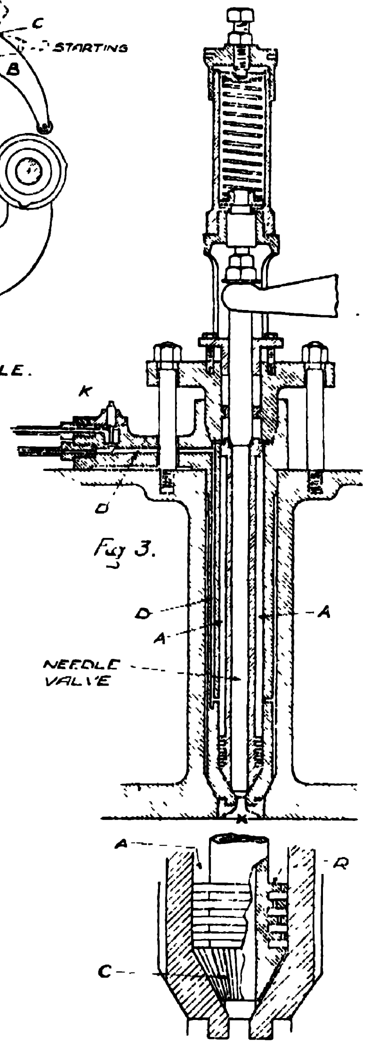
AIR-INJECTION DIESEL ENGINE DETAILS



CONTROL HANDLE.



FUEL PUMP



FUEL INJECTION VALVE

The cylinder head is detachable, and contains the inlet and exhaust valves, *a* and *b*, working on renewable valve seatings, and worked by cams from the half-time shaft. It also contains the injection valve, *c*, and air-starting valve, *d*, worked off cams which can be brought into play as desired by the starting handle, but only one at a time.

4. The **air compressor** is generally a 2- or 3-stage machine driven off the crankshaft or connecting rod, and calls for no special comment.

From the compressor the air passes through a cooler to a blast (air-injection) reservoir (bottle) of sufficient capacity to absorb fluctuations of pressure, and fitted with suitable distributing valves, one of which communicates with the fuel-injection valves and another passes surplus air to the storage reservoirs provided for starting purposes.

5. A **fuel-injection valve** is shown on Pl. **78**, Fig. 3. The fuel force pump delivers the charge of oil to the branch, F, thence along the duct, DD, and into the annular space, AA, surrounding the cast-iron guide of the needle valve. The pulverizer comprises several steel washers, R, each drilled with about 20 holes, $\frac{1}{10}$ in. in diameter; these holes are staggered as indicated, so that the oil takes a tortuous path through them, and the rings are kept apart by distance washers. Below these pulverizing washers and fitted to the bottom of the needle-valve guide is a conical head, C, on the outer surface of which are formed about twenty channel grooves, through which the oil charge passes before reaching the spraying nozzle; immediately after passing the nozzle, it enters the combustion chamber by the steel expanding orifice in the nickel-steel flame plate, X.

The annular space, AA, is in constant communication with the air-blast reservoir during the running of the engine, through a branch entering its upper portion which is not shown in the figure. This space is always under the high pressure of the air reservoir, and immediately the needle valve rises from its seat the charge of oil is driven with great velocity through the pulverizer washers and cone channels, and enters the combustion chamber through the expanding nozzle in the form of a uniformly diffused mist.

The test cock, K, is for ascertaining that the oil supply is uninterrupted.

On account of the serious pre-ignition effects that may result from the leakage or sticking up of the fuel-inlet valve, it should be regularly and carefully cleaned. The amount of lift of the injection valve is regulated by altering the tappet clearance.

6. **Starting** is effected by introducing air at a high pressure from the starting reservoirs into the cylinder by a cam-actuated valve. The same lever which brings the starting cam into play puts the injection cam out of action.

Pl. **78**, Fig. 1, shows the action. The levers, A and B, actuating the injection and starting valves respectively, pivot on the eccentric sleeve, C, which can be moved relative to the fixed pin, D, by the starting handle.

With the handle in the *neutral* position, the tappet clearances of both valves are such that the cams do not actuate them.

When the handle is in the *start* position (horizontal), the tappet clearance of the starting valve is practically nil, and a charge of high-pressure air can be admitted to the cylinder automatically by the cam at the right moment (*i.e.* when the piston is barred round to a point just after inner dead centre on the power stroke).

When the handle is in the *run* position, the tappet clearance of the injection valve is correct, and that of the starting valve so large that it is not actuated by its cam, and is, therefore, out of action.

98. *Instructions for working Diesel engines* (*air-injection*)

1. The following paragraphs are given as typical working instructions for Diesel engines. They must, of course, be varied in detail for engines of different manufacture.

2. **Preparation for starting.**—The engine, like all other I.C. engines, must always be started light. The flywheel should be barred round until the starting cylinder crank is a little over the top centre and the starting valve is just about to open. During this process the inlet valve is held open by the lever provided for that purpose.

The lubricators should then be examined, filled, and adjusted, and all pins and joints lubricated. For the air valve and exhaust-valve spindle use only a little clean paraffin ; for the cams and rollers use cylinder oil. In cold weather all lubricating oil should be warmed before use.

Place the lever, E on Pl. **78**, Fig. 1, in the middle position ; fill the pipe between fuel filler and fuel valve with gas oil by opening the cock in the filler and the test cock in the fuel valve, and turn the lever on the fuel pump to *filling*. As soon as oil runs out of the test cock, close it ; then set the fuel-pump lever to *running*, and release the inlet valve.

To prevent oil from getting into the cylinder whilst filling, under no circumstances leave the lever of the fuel pump longer in the *filling* position than is necessary to fill the fuel pipe.

The cooling water should now be turned on.

3. **Starting.**—After ascertaining the pressure in the air vessels by opening the manometer valves, D, E, and H on Pl. 77 (only one at a time), open the valve C on the air-injection vessel, and thus establish communication between this vessel and the air compressor; also open valve B, which establishes communication with the fuel valve. Finally, open valve A or K on one of the starting vessels.

By placing the starting lever in its lowest position the starting valve will be opened and compressed air will enter the cylinder, thus setting the engine in motion. After about four exhausts, the starting lever is brought to its top position, and firing should then commence. Valve A or K on the starting vessel must immediately be closed and the compressor throttle valve opened wide.

In the case of engines with several cylinders, first bring those levers which will not cause the starting valves to be opened into the starting position; then bring the remaining lever into the starting position, thus causing the starting valve to open and compressed air to enter the cylinder. After several revolutions, move the levers to the top position, one after the other, and firing will follow. Then proceed exactly as before.

As soon as normal speed is obtained, the engine can be loaded, gas oil shut off, and heavy fuel oil turned on.

Owing to the air compressor delivering a quantity of air, the pressure in the injection vessel will rise; as soon as it reaches the pressure necessary for good combustion, the starting vessels can be refilled by opening the manometer valve, D, on the air injection and either E or H on the starting vessels, but only so much that the pressure in the injection vessel necessary for good combustion is still maintained. After reaching the required pressure in the starting vessels, the air compressor should be throttled so that it only delivers the amount of air required for injection.

4. **Running.**—When the engine is running, watch carefully the pressure in the air-injection vessel, the condition of the exhaust, the temperature of the cooling-water outlet, and the lubricators and lubricating arrangements. Keep the last named filled, lubricate cams and rollers occasionally, and ensure that the lubricating rings in the main bearings are revolving freely. All accessible bearings should be felt with the hand to ascertain if they are running cool.

The air-injection pressure should vary from 600 to 900 lb. per square in., from no load to full load. If the pressure is too low, the exhaust will be smoky; if too high, the engine will knock.

Black smoke is a sign of incomplete combustion, caused by too low a pressure, overload, dirt in the pulverizer, leakage

past the valves, unsuitable fuel, or over-lubrication of the working cylinder.

The cooling water should be regulated for an outlet temperature of 120° to 130° F.

5. **Stopping.**—It is advisable to run for 5 minutes on gas oil before stopping.

After the load has been thrown off, the fuel-pump lever is brought to *stop*, and valve B on the air-injection vessel, which communicates with the fuel valve, is closed. The engine will slow down, and, before stopping, the inlet valve should be held open by the arrangement provided.

After the engine stops, place the starting lever in the middle position and close the fuel and cooling-water cocks. The crank is then brought to its lowest position. It is important that all valves on the air vessels should be tightly closed to avoid leakage.

The engine should now be carefully cleaned and all oil-drippers emptied; loose nuts, pins, and keys should be properly tightened, and irregularities noticed whilst running promptly attended to.

In frosty weather all water pipes and jackets should be drained.

After any alteration has been made to the engine, it should be barred round several times to ensure that all working parts are clear.

After standing idle for several days, the engine should be run light for a short time. Before long stoppages the engine should be well greased externally. The pressure in the air vessels should be frequently examined, and if it falls below 550 lb. the vessels should be recharged.

6. **Valves.**—All valves must be kept absolutely tight, as otherwise the engine may fail to start and the exhaust will be smoky. When putting the valves back, great care must be taken to ensure that the casings are also tight on their seatings and that they are not twisted.

Each time before starting, the glands of the fuel valve should be lubricated. It is most important that the needle valve should work freely.

When the valves are in position, the roller clearance must be checked and, if necessary, adjusted by the set screw on the valve levers to give exactly the same clearance as when the engine was erected.

7. **Fuel pump.**—The length of the rod controlling the suction valve should never be interfered with.

8. **Air compressor.**—The piston and valves must be examined from time to time and cleaned; at the same time, the piston rings should be examined and cleaned if necessary.

9. **The air vessels.**—The pressure in the air-injection vessels must be between 600 and 900 lb. per square in., according to the load. The pressure in the starting vessels should be kept at about 700 lb.

The water in the air vessels, due to condensation, must be drawn off daily whilst the engine is running.

The pressure in the injection vessel (blast bottle), if too low, can be increased by opening the manometer valve, D, on the air-injection vessel, and E and H on one of the starting vessels, without losing too much pressure in the latter.

It is, therefore, advisable to keep the pressure in the reserve starting vessel a little higher than the pressure actually required for running. By throttling the blast-control valve, the injection pressure may be regulated below that of the bottle. It is thus possible to pump up the starting vessels to 900 lb./sq. in. while the blast pressure is only 600 lb./sq. in. as required for running light.

10. **Fuel and filters.**—All kinds of petroleum, crude or refined, and most distillates can be used as fuel, provided they do not contain acids, tar, or other impurities and are not too thick. If the oil contains much foreign matter, an extra filter should be fitted on the main storage tank.

All fuel tanks and filters must be cleaned out from time to time, and it is advisable to provide cocks at the bottom to drain off the water and impurities.

11. **Lubrication.**—For cylinders, good cylinder oil, not too thick, should be used. (*See* Table **ZA,** page 604.) For the air-suction valve and exhaust valve, only clean paraffin should be used.

All lubricating oil should be filtered before use.

For air compressors, a special oil is required.

99. *Diesel engines (solid-injection), general principles*

1. This type is frequently known as the "*Cold Starter,*" an unsatisfactory name, as the characteristic of starting from cold on heavy oil without the help of any ignition device is one which it shares with the air-injection Diesel engine.

2. In order that heavy oil may be burnt in an engine cylinder without the use of a hot bulb or other hot surface, two conditions must be fulfilled.

(*a*) The air in the combustion chamber must be raised to a temperature sufficient to ignite the oil; this is attained in both types of Diesel engines by the use of a very high compression pressure as described in Sec. **97.**

PLATE 79.

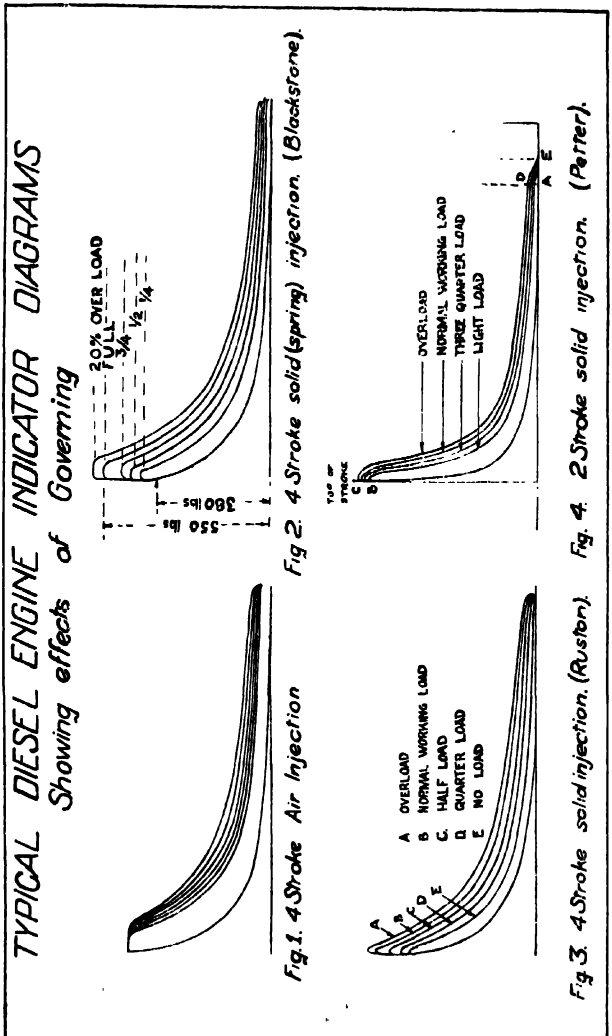


Fig.1. 4 Stroke Air Injection

Fig 2. 4 Stroke solid (spring) injection. (Blackstone).

Fig 3. 4 Stroke solid injection. (Ruston).

Fig. 4. 2 Stroke solid injection. (Petter).

PLATE 80.

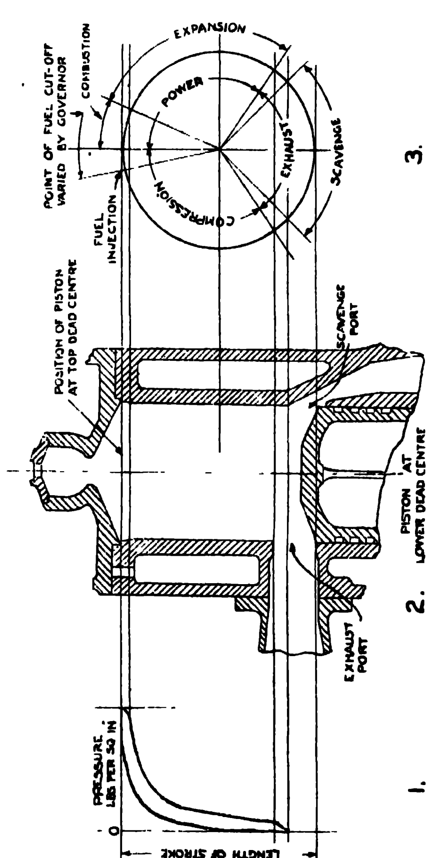


DIAGRAM SHOWING SEQUENCE OF OPERATIONS IN ATOMIC DIESEL ENGINE

Permission of Pellers Ltd

(*b*) Since the fuel will not vaporize at ordinary temperatures, it must be "atomized," *i.e.* reduced to a very finely divided spray—practically a mist—in order that the heated air may come in contact with every particle of fuel. This is accomplished in the air-injection Diesel engine, as already explained, by means of an air-blast; in the solid injection engine it is accomplished by a purely mechanical atomizing device, consisting essentially of a pump and a fine nozzle, through which the fuel is forced by a pressure of 1,000 lb. per sq. in. or more.

The development of the atomizer has rendered solid injection possible, and the satisfactory running of these engines depends to a very great extent on this component.

3. As compared with the air-injection engine, the solid injection engine possesses the advantage of simplicity. The compressor is dispensed with, and with it the necessity for regulation and adjustment of the blast pressure and the risks attendant on careless or unskilful adjustment of the same. It is, therefore, more suitable than the air-injection type for use in comparatively unskilled hands.

4. The gain in mechanical efficiency, due to the absence of a compressor, is offset by lower thermal efficiency, but the overall efficiency approaches that of the Diesel engine.

5. Compression pressures are slightly lower than with air-injection Diesel engines, about 420 lb. per sq. in. being a common figure, but maximum explosion pressures are higher. This is due to the fact that combustion is more rapid than when an air-blast is used. In the air-injection engine the pressure does not rise appreciably above the compression pressure, but remains at that level for a considerable portion of the working stroke. In the solid-injection engine the pressure rises immediately to nearly 600 lb. per sq. in. but falls off at once. Compare indicator diagrams (Pl. **79**, Figs. 1 and 3).

In this respect the air-injection Diesel engine has an advantage; to deal with the higher pressure the solid-injection engine requires greater strength, and it does not run quite so sweetly, but always thumps to a certain extent.

6. Combustion does not appear to be quite so perfect as in the air-injection engine, and it is more difficult to obtain an absolutely colourless exhaust.

7. The fine nozzles of the atomizers are readily choked; careful filtration of the fuel oil and periodical cleaning in paraffin should, however, obviate trouble of this nature.

8. The majority of solid-injection engines work on the four-stroke cycle, and these are made by a number of makers

in horizontal or vertical forms, with from one to eight cylinders, and developing from 10 to 150 B.H.P. per cylinder.

9. While a number of makers produce two-stroke engines using airless injection, the majority of these are not strictly cold-starting engines. A notable exception is the Petter "*Atomic*" Diesel. In construction and action this engine is substantially the same as the two-stroke semi-Diesels referred to in Sec. **96**, but in the Atomic Diesel the compression pressure is increased to about 400 lb./sq. inch and the hot bulb is dispensed with.

A fuel and port timing diagram is given in Pl. **80**.

These engines compare very favourably with four-stroke engines of equal rating as regards fuel consumption and the same range of fuels can be used.

The atomizer or spraymaker in solid-injection engines is usually of similar type to that used on semi-Diesel engines which is illustrated on Pl. **74**, Fig. 2, and described in Sec. **96**, the injection of a definite quantity of fuel suitable for the load being effected and timed by a fuel pump controlled by the governor. As there is no hot bulb, however, cooling of the atomizer is unnecessary, but greater care in the manufacture and fitting of the fuel, injection system is necessary on account of the higher injection pressures which have to be employed (2,500 lb./sq. inch or more).

10. In the Blackstone and Davey-Paxman engines a somewhat different system is adopted—the Paxman Spring Injection System. In this system the pump merely delivers a measured quantity of fuel (as determined by the governor) to the injection device on the cylinder head, and the latter effects injection of the fuel at the correct moment by means of a spring. Pls. **81** and **81***a* show the system; the action is as follows (Pl. **81**, Fig. 1): The fuel pump has filled the fuel chamber and pushed the injector plunger outwards (the spring not being compressed). The injector valve is held on its seat by the action of the inner spring combined with that of the outer spring (transmitted by the spring rod and bell-crank lever).

(Fig. 2.)—The injector lever, operated by an eccentric on the half-time shaft, compresses the main spring, forcing the injector plunger against the oil and so closing the non-return valves.

(Pl. **81***a*, Fig. 3.)—The injector lever has compressed the external spring slightly, taking its pressure off the injector valve. The pressure of the oil is now sufficient to overcome the internal spring and lift the valve, and injection takes place.

It is claimed that this system gives a more sharply defined commencement and finish to the injection than is possible

PLATE 81.

PAXMAN SPRING INJECTION

CARTER'S PATENTS

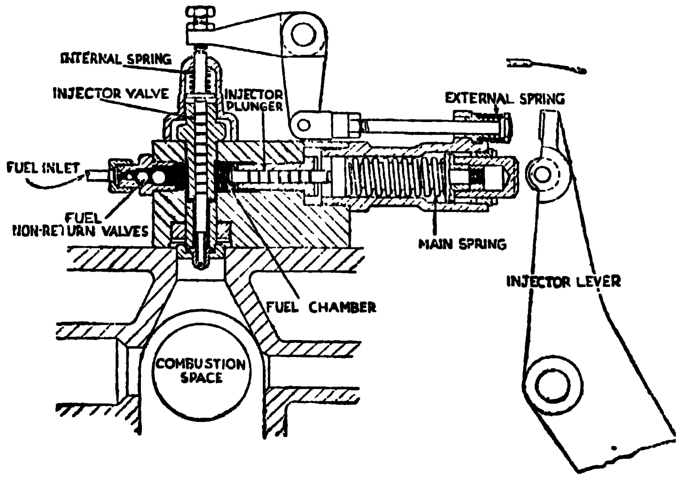


Fig. 1.

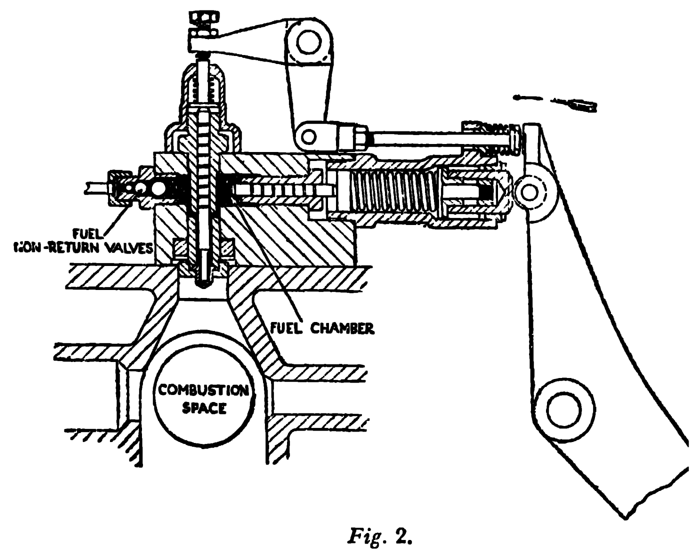


Fig. 2.

[*Permission of Messrs. Davey, Paxman & Co., Ltd., Colchester.*]

PLATE 81(*a*).

PAXMAN SPRING INJECTION

CARTER'S PATENTS

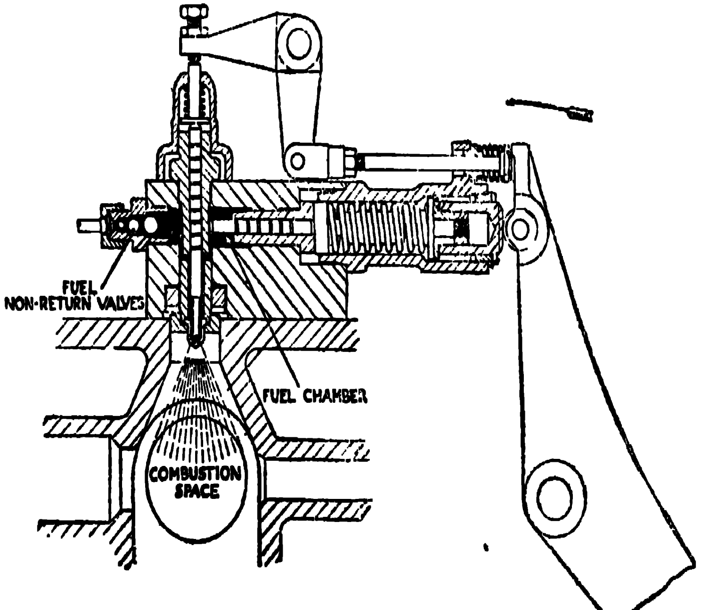


Fig. 3.

with cam-operated injection, that its efficiency is not affected by engine speed, and that more prolonged and more perfect combustion is obtained. The indicator diagram (Pl. **79**, Fig. 2), which shows a flat top approximating to that given by an air-injection Diesel engine rather than the sharp peak of the typical solid-injection engine, bears this out. The explosion pressure, though higher than that of the air-injection Diesel engine, is lower than is normal with cold-starters. A lower compression pressure is used, *i.e.* about 380 lb./sq. in.

Another advantage of the system is the elimination of high-pressure fuel-piping ; the pump pressure is not more than 15 lb./sq. in.

Against these advantages must be set a certain loss of simplicity and multiplication of small working parts on the cylinder heads. The engine is very sensitive to the adjustment of the injector lever clearance, which affects the time of injection.

11. In multi-cylinder engines it is important, in order to secure smooth running and maximum efficiency, that the load should be carried equally by all the cylinders. In most cases this is obtained by providing means for regulating the supply of fuel to each cylinder separately ; each cylinder has its own fuel pump, which measures out the required amount of fuel, this amount being controlled (*a*) by the governor, (*b*) by hand regulation. While this system permits of compensating for irregularities in the efficiency of the atomizers, &c., and in skilled hands probably allows of the closest possible regulation, it is, however, dependent on the skill of the operator, and offers possibilities of bad regulation. To obviate this disadvantage and render the engine as foolproof as possible, some multi-cylinder engines are fitted with a single pump (up to 4 cylinders) or two pumps (for 5 and 6 cylinders) and a distributor. The pump makes one stroke for each explosion, delivering the oil to the distributor, from which it is sent to each cylinder in turn.

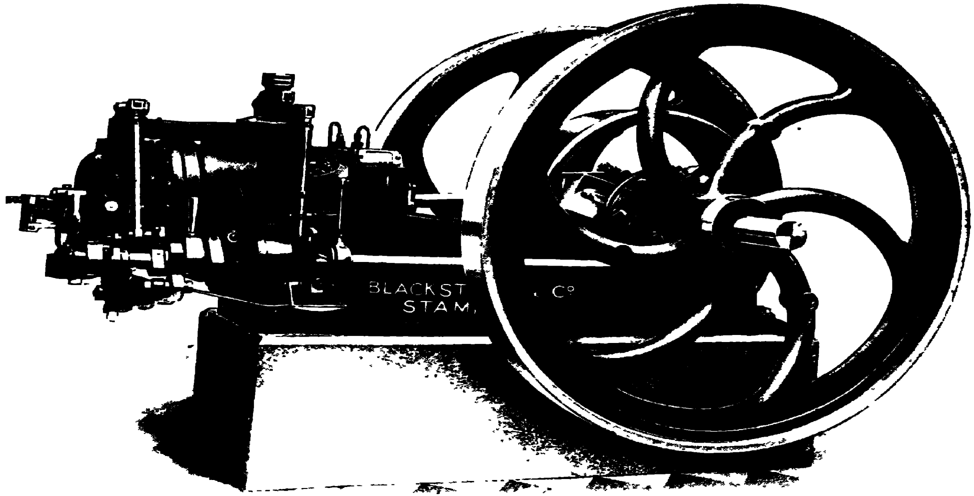
It is doubtful whether this system is as satisfactory as one with separate fuel pumps and individual control.

12. **Fuel and fuel consumption.**—As with the air-injection Diesel engine, very low-grade and heavy fuel oils may be used, such as crude petroleum, tar oil, palm oil, &c. Best results are obtained with a medium to fairly heavy fuel oil, specific gravity from about 0·89 to 0·92, but heavier oils can be used with perfectly satisfactory results if they are heated to enable them to flow freely. A fuel consumption of 0·40 lb. per B.H.P. hour at full load can be obtained with the larger engines.

To face p. 404]

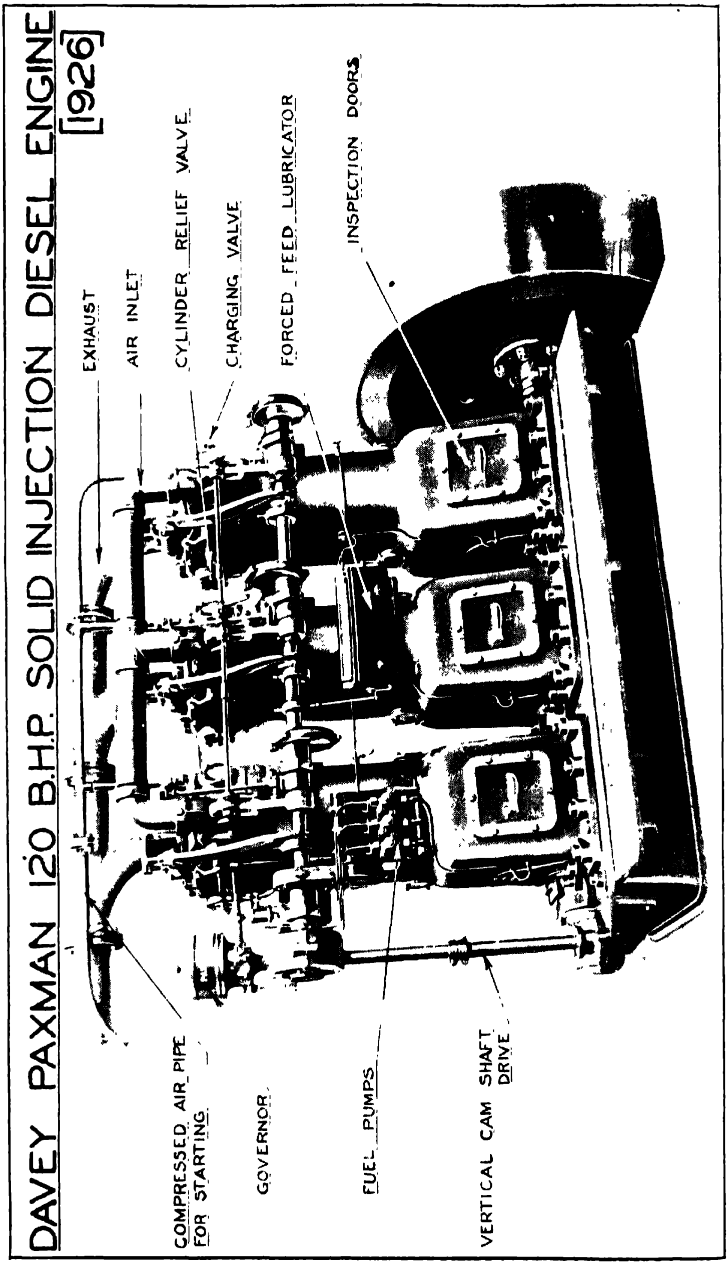
PLATE 82.

THE BLACKSTONE "SPRING INJECTION" DIESEL ENGINE

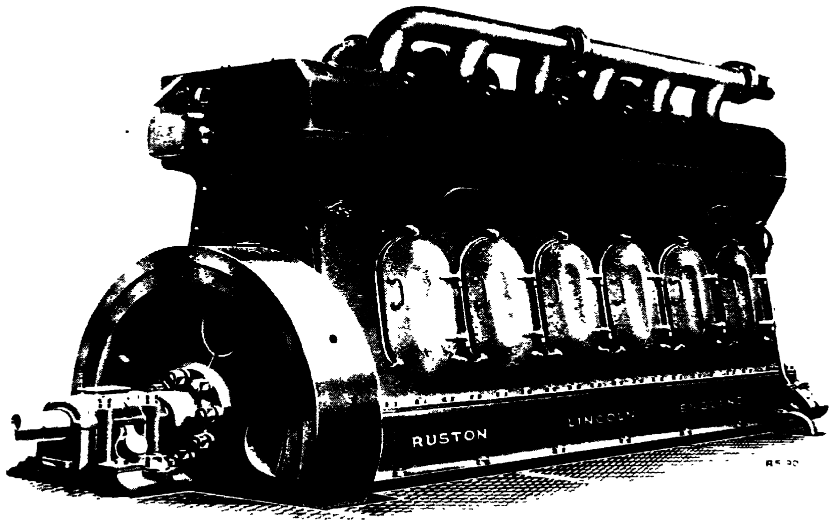


Permission of Blackstone & Co., Stamford.]

From a Photograph of a 17 B.H.P. representing Sizes 6 B.H.P. to 45 B.H.P.


DAVEY PAXMAN 120 B.H.P. SOLID INJECTION DIESEL ENGINE [1926]
EXHAUST
AIR INLET
CYLINDER RELIEF VALVE
CHARGING VALVE
FORCED FEED LUBRICATOR
INSPECTION DOORS
COMPRESSED AIR PIPE FOR STARTING
GOVERNOR
FUEL PUMPS
VERTICAL CAM SHAFT DRIVE

RUSTON 330 B.H.P. SOLID-INJECTION DIESEL ENGINE [1932]



Illustrating Engine Mark 6VER.

13. Typical examples of solid-injection Diesel engines are shown in Pls. **83** and **84**, and the principal dimensions, &c., of these engines are given below :—

Pl. **82**, *Blackstone Model C.S.I. Horizontal* (1928).
B.H.P. 17, r.p.m. 250.
Single cylinder, bore 7½ in., stroke 15 in., overall dimensions 5 ft. × 4 ft. × 4 ft. high.

Pl. **83**, *Paxman Model* 3 *V.H. Vertical* (1926).
B.H.P. 120, r.p.m. 333.
3 cylinders, bore 10 in., stroke 15¼ in., overall dimensions 124 in. × 65 in. × 98 in. high.
Minimum height of crane hook 114 in.
Flywheel 69 in. dia. Weight 80 cwt.

Pl. **84**, *Ruston Model* 6 *V.E.R. Vertical* (1932).
B.H.P. 330, r.p.m. 428.
6 cylinders, bore 11 in., stroke 14½ in., overall dimensions 181 in. × 55 in. × 94 in. high.
Minimum height of crane hook 115 in.
Flywheel 56 in. dia. Weight 238 cwt.

Comparing the engines shown in Pls. **83** and **84**, note that the more modern design runs at a higher speed and therefore, size for size, it is smaller, lighter, and cheaper. Also, it is totally enclosed, thus being rendered practically dust-proof. The working parts, however, are just as easily accessible as in the older design—hinged doors give access to the crank case and detachable covers to the camshaft, &c.

100. *Instructions for working Diesel engines (solid-injection)*

1. **Starting.**—Small engines can be turned by hand on half-compression sufficiently fast to carry them over full-compression when the half-compression cam is put out of action. The fuel pump being brought into action at the same time, the engine should fire at once without the use of any heated plug or other device. In some cases (*e.g.* Blackstone engines up to 100 H.P.), a removable plug with some form of igniting device is used to enable the engine to fire on half-compression for a few revolutions, after which the speed will be sufficient to carry the engine over full-compression, when ignition becomes normal.

In most cases, however, starting is effected by means of compressed air. An air-bottle is charged to about 200 to 300 lb. pressure by using one cylinder of the engine temporarily as an air compressor, or by means of a small auxiliary compressor, which may be belt-driven from the engine or driven by an independent source of power. It should be noted that

the compressor is used for short periods only, not continuously, as in the case of the air injection Diesel engine.

For starting purposes, cam-operated valves are provided to admit air to the cylinders (in the case of multi-cylinder engines only two or three cylinders may be so fitted) and half-compression cams are also provided on the cam-shaft in some cases. To start, the engine is barred round until the crank of one of the starting cylinders is a few degrees past top dead centre on the firing stroke, the half-compression cams (if fitted) and starting-valve cams are brought into action, and the fuel pumps put out of action, and air admitted from the air-bottle. After a few revolutions, the engine (if running on half-compression) is put on full-compression and the fuel pumps brought into action, when the engine should fire. An automatic valve prevents any blow-back into the starting system when the engine fires.

The engine should be allowed to run up to full speed on light load, when the governor will come into action and cut down the fuel supply ; the load may then be put on.

Even large engines can be put on load in about one minute, starting from cold, if all is in order.

For routine attention to valves, &c., read Sec. **102**, and makers' handbooks.

2. **Failure to start.**—If the engine fails to start, the most probable cause is that fuel oil is not being delivered to the cylinders. It is important to ensure that oil pipes are full before attempting to start, by working pump by hand until it feels " solid." If a distributor is fitted, this must be done with each crank in the firing position in turn.

Leaky suction joints, blocked filter, or air-locks are other likely causes of fuel not reaching the cylinder. If all these points have been attended to, the atomizer should be dismantled and cleaned, and if there is still no improvement, the pump or injector mechanism should be carefully overhauled and cleaned.

3. **Faulty running.**—Knocking or thumping on load, not noticeable when running light, may be due to pre-ignition. This can only be caused by too early injection of the fuel. If injection is controlled by the pump, timing is set by the fuel-cam, and is not likely to alter. The cam, however, is provided with an adjustment. With spring-injection, early injection may be caused by the injector-valve spring being too weak or by the main spring being too strong, as well as by incorrect setting of the eccentric operating the injector.

It may be necessary to alter the time of injection if the fuel is changed. Generally speaking, the heavier the oil, the earlier the injection required.

Thumping, not amounting to pre-ignition, may be caused by too high compression. As already stated, however, solid-injection engines always thump slightly on load; if the thumping appears excessive, indicator diagrams should be taken, both for firing and for compression, the latter being taken by cutting out the fuel pump momentarily while the diagram is taken. Pre-ignition will be shown by an unusually high and sharp peak to the firing diagram, the compression being unaffected.

Knocking which persists when running light must be due to mechanical defects.

Imperfect combustion is indicated by smoky exhaust, dirty piston (possibly sticking), overheating, and high fuel consumption. It may be caused by (*a*) bad atomization, (*b*) low or faulty compression, (*c*) late injection, (*d*) overloading.

101. *High-speed Diesel engines*

1. Thoroughly satisfactory designs of low-speed (200–300 r.p.m.) heavy-oil engines, both air and airless injection, having been developed and well tried out for many years, it is natural that manufacturers should give attention to producing higher speed engines which are lighter, smaller, and cheaper. For stationary engines of moderate size (say 100–500 B.H.P.), speeds of 500–800 r.p.m. are now becoming common.

2. The term *high speed,* however, is usually applied to the comparatively small type (say up to about 50 B.H.P.), running at speeds from 1,000–3,000 r.p.m., which has been developed during the past few years for road vehicles and light marine craft, popularly known in this connection as *compression-ignition* engines.

The weight–power ratio of some designs approaches that of the petrol engine. 15 lb./B.H.P. is common, compared with 11 lb./B.H.P. for the petrol engine.

In small units it is possible to use higher stress values than would be permissible in large units, since the special high tensile steels employed in the construction of these engines have not so far proved their dependability in large forgings.

While the design and operation are generally the same as the ordinary types of heavy-oil engine, the high speed introduces certain difficulties apart from that of mechanical stresses.

In some designs the limiting speed is stated to be the gas velocities at the air and exhaust valves, but the real trouble arises in regard to the requirements of fuel injection which, even in low-speed engines, are exacting. The fuel pump and atomizer must inject a small measured quantity of fuel during a period corresponding to about 5° of crank angle, delivery

must start and stop smartly, and therefore air injection cannot be employed.

To ensure the requisite degree of atomization and penetration, very high injection pressures (up to 10,000 lb./sq. in.) have been employed in some designs, but the use of such high pressures in the fuel system, with the necessary small holes in the atomizer, has caused a good deal of trouble. Better results are now being obtained by so shaping the combustion chamber that the air enters at high velocity with a rotational swirl and the resulting *turbulence* gives satisfactory operation with much smaller injection pressures (1,000–2,000 lb./sq. in.).

3. The *Bosch* fuel pump, which is largely used on low-speed solid-injection Diesel engines, is quite suitable for the high-speed designs, so also is the *Benes* fuel pump, shown in Pl. **85**, which is of British design and manufacture.

Fig. 1 shows a four-cylinder model; Fig. 2, one element in section; and Fig. 3 (*a*) to (*e*), various positions of the plunger.

Referring to Fig. 2, the plunger *A* works in a sleeve *B* with inclined faces. The sleeve is carried in the pump barrel *C*, the former being fixed relative to the barrel. Rotatably mounted about the pump barrel at the lower end is a two-piece sleeve *D* which is operated by a control arm *E*. This arm is provided with slots at its lower end in which projections *F* on the plunger engage, so that rotation of the sleeve *D* by means of the arm also rotates the plunger, the slots being so arranged as to permit the plunger to reciprocate while it is being rotated. The plunger is cam-operated in the usual manner, being returned on the suction stroke by the spring *G*. The plunger, it will be noted, is guided by the cup-shaped member *H*. The construction of the plunger is such that there is no side-thrust on it. The upper part of the pump plunger is provided with a long central hole, communicating with relief ports, formed by drilling a radial hole right through the plunger at the end of the vertical central hole. The suction chamber of the pump is formed by the space in the pump housing which surrounds the top part of the barrel.

The spaces formed by the inclined faces on the sleeve *B* are, like the radial hole in the plunger, in direct communication with the suction chamber of the pump.

The operation of the pump can be followed from Fig. 3. (a) shows the pump plunger at the bottom of the suction stroke. As soon as the ducts in the barrel and the spaces formed by the inclined faces communicate with the suction chamber, these spaces, together with the clearance space above the plunger, are filled with fuel. (b) shows the point at which injection is commencing—that is, when the suction ports are closed by the plunger. Injection is carried out over the period represented by the travel of the pump plunger

PLATE 85.

BENES FUEL PUMP.

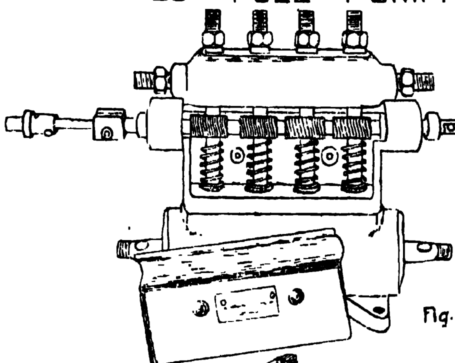


Fig. 1

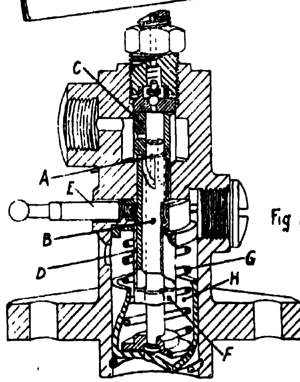
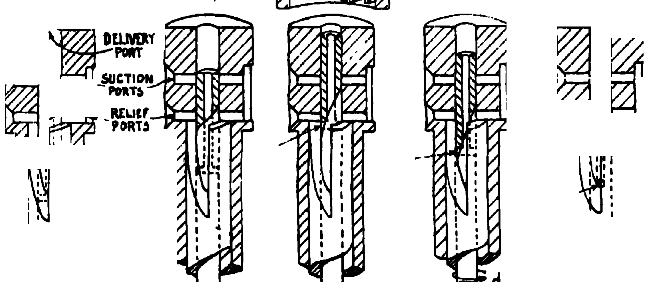


Fig 2



a BOTTOM OF STROKE

b INJECTION COMMENCING.

c TERMINATION OF INJECTION (FULL LOAD)

d TERMINATION OF INJECTION (PARTIAL LOAD)

ENGINE STOPPED

Fig 3.

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from position (b) to position (c). The arrows in the diagrams indicate the point at which the radial plunger port is almost uncovering the relief port. As soon as communication is established between the radial plunger port and the relief port in the body of the pump, an instantaneous destruction of pressure naturally occurs and fuel injection ceases. (d) is the position when the engine is on partial load, the plunger having been rotated through a suitable angle in the direction of the arrow shown at the bottom of the rod. In this way, on the up-stroke of the plunger the radial relief ports are uncovered earlier by the inclined faces on the sleeve, so that the pressure is relieved earlier and the quantity of fuel injected into the cylinder is correspondingly reduced. When it is desired to stop the engine, the plunger is rotated through a further angular distance until it assumes the position shown at (e), when obviously no fuel can be pumped up.

The pump can be used with any design of atomizer (or injector nozzle).

4. Although the high-speed heavy-oil engine is of comparatively recent introduction and cannot yet be said to have been thoroughly tried out, it is reasonable to assume that its reliability will be at least equal to that of the petrol engine, in which case it should prove very suitable for small portable generating sets, pumping sets, &c.

Somewhat higher combustion pressures are employed than in the ordinary low-speed engine.

The full-load fuel consumption of small engines of 9½ B.H.P. per cylinder, is about 0·41 to 0·45 lb./B.H.P. hour, which is about half the weight of fuel required in a petrol engine of corresponding size and speed.

Moreover, the heavy fuel-oil is relatively cheap and can be more safely stored.

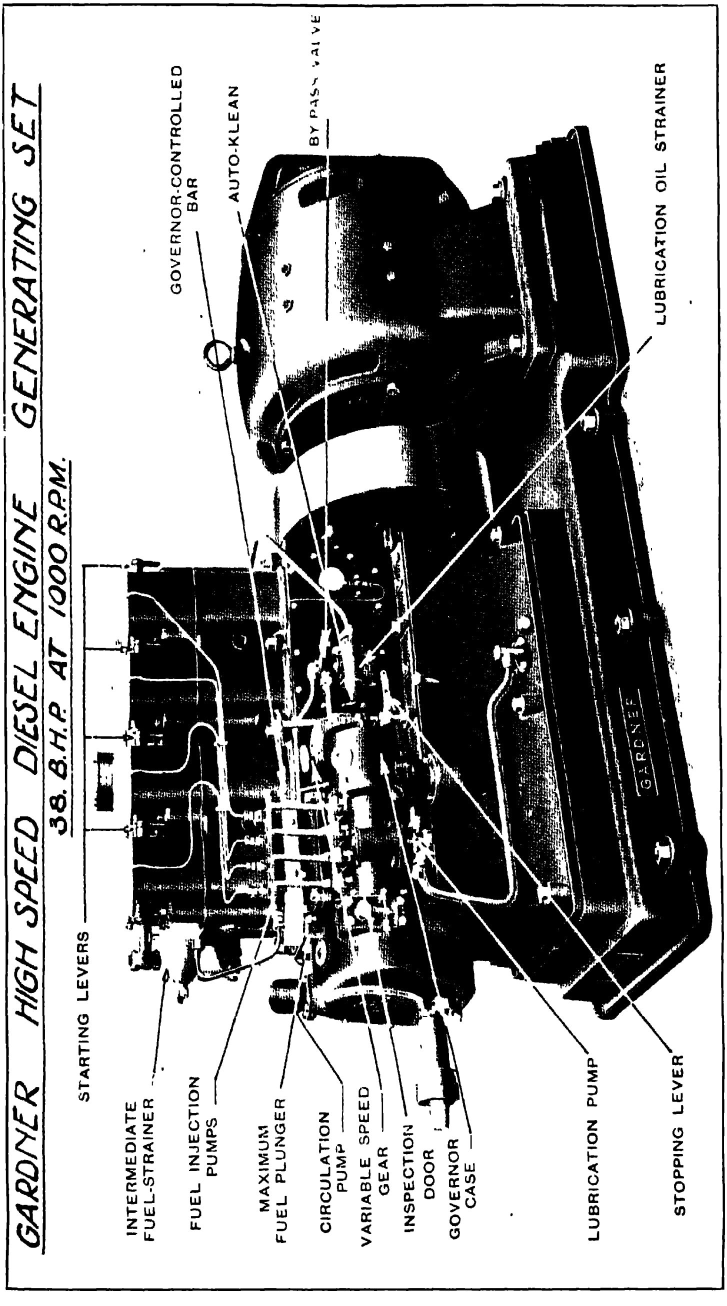
Pl. **86** shows a four-cylinder *Gardner* high-speed heavy-oil generating set. The rated B.H.P. is 38 at 1,000 r.p.m. for continuous running, but the engine can be run up to 1,300 r.p.m. and will then develop up to 50 B.H.P. for intermittent demand in a road vehicle.

The overall dimensions of the engine are 55 in. by 25 in. by 40 in. high, and the weight is 29 cwt.

It is started from cold, by hand, simply by cranking. Forced lubrication is employed throughout.

102. *Routine inspection and maintenance of Diesel engines*

1. The heavy oil engine gives singularly little trouble as long as it is properly looked after; but to ensure that parts receive the necessary care and attention it is essential that a regular programme of overhauls and examinations should be prepared and rigidly adhered to.


GARDNER HIGH SPEED DIESEL ENGINE GENERATING SET
38. B.H.P. AT 1000 R.P.M.
STARTING LEVERS
INTERMEDIATE FUEL-STRAINER
FUEL INJECTION PUMPS
MAXIMUM FUEL PLUNGER
CIRCULATION PUMP
VARIABLE SPEED GEAR
INSPECTION DOOR
GOVERNOR CASE
LUBRICATION PUMP
STOPPING LEVER
LUBRICATION OIL STRAINER
GOVERNOR-CONTROLLED BAR
AUTO-KLEAN
GARDNER

The type of engine generally dealt with in the following notes is the blast air-injection Diesel. This has been chosen as being rather more complicated than the solid-injection type. Both types of engine have very many parts in common, and what is stated here about the one is equally applicable to the other, unless specially qualified in the notes.

2. **Fuel valve.**—Upon the condition of the fuel valve depends the efficient and economical running of the engine. It is, therefore, suggested that it should be attended to every 6–8 *hours' running*. It is fully admitted that this is an ideal and that in many installations it may be impossible to shut down to enable this to be done. Such cleaning, however, should be carried out wherever possible. The time of the shut-down may be very much decreased by keeping a spare fuel valve ready to replace the one being cleaned.

In the case of the solid-injection type engine, there are many differing designs of fuel valve, either with a packed or packing-less type of spindle. While the general principles are the same in all cases, the instructions given in the maker's handbook should be closely followed.

The atomizer (or pulverizer) is the part most likely to require attention ; as a matter of precaution it should be taken to pieces and carefully cleaned with paraffin after every 100 *to* 200 *hours' running*, according to the quality of fuel oil. At the same time the strainer in the oil tank should be cleaned with paraffin. The atomizer can be tested by connecting up to the fuel pump, and working the latter by hand, directing the atomizer at a sheet of paper about 2 feet away. The spray should be evenly spread over an area (depending in shape on the design of the nozzle) without any large drops. When the paper is held about 4 feet away from the nozzle, the whole of the spray should be dissipated in the form of mist before it reaches the paper. Drops large enough to carry this distance indicate imperfect atomization. The nozzle may be dirty or worn, or the plunger valve may require grinding in with fine Crocus powder.

Perfect combustion cannot be obtained without perfect atomization.

The valve seating must be maintained, and rubbing in with oil alone should be sufficient if done as frequently as recommended above. Abrasives should not be used in any case—they are difficult to remove from the seat and cause rapid wear. Where difficulty is met in obtaining a good seating, the valve should be rubbed in quite dry and any hard portions removed with a small smooth file. This should be repeated until an even bearing surface is obtained, and then finished off with liquid metal polish and a *little oil*.

With the air-injection Diesel, the flame-plate hole slowly

becomes choked and eventually leads to "dribbling." It should therefore be "mucked out" with a piece of soft wire at the time that the fuel valve is taken down.

3. **Exhaust valve.**—The exhaust valve should be taken down, cleaned and ground once in about every 100 *hours*. It is not necessary to remove all pit-marks so long as a good all-round seating is secured. Constant grinding out of all pit-marks will reduce the life of the valve and seating without improving its efficiency.

4. **Inlet valve.**—It is as well to look at this when the exhaust valve is taken down, but it is unlikely that any action will need to be taken until after 600–700 *hours' running*.

5. **Crank alignment.**—Considerable trouble has been experienced in the past with broken crankshafts. Improved methods of manufacture, however, have now reduced such occurrences to a minimum, and with proper care they should not take place.

The possibility of a settlement of the foundation after the erection of an engine must be borne in mind, and it is always possible that the bearings may lose their alignment through unequal wear. The first signs of bearings being out of line are usually excessive end-movement of the shaft when running, flywheel running out of truth, and uneven heating of the bearings, the high ones tending to overheat while the low ones heat more on the top half than on the bottom half.

In any case the bearings should be tested for alignment every six months if the engine is in regular use. With small engines, and single-cylinder engines, it is usually most convenient to dismantle the engine and test with a straight-edge (or better, if available, a mandrel accurately made to fit in the bearings in place of the shaft). With large multi-cylinder engines the method described below should be used.

It will be appreciated from Pl. **23**, Fig. 13, that where a pair of adjacent bearings are out of alignment, either horizontally or vertically, or both, there will take place during each revolution an opening and closing of the crank webs. If the out-of-alignment is serious, this concertina-like action of the crank webs causes overstress of the metal resulting in fatigue, with ultimate fracture through the web. A belated correction of bad alignment may delay but cannot prevent eventual failure, if the shaft has been subjected to a sufficient number of applications of an undue stress.

Measure the distance between the crank webs at top dead-centre, at bottom dead-centre, and at the two intermediate positions. Differences between the measurements in the vertical positions indicate out-of-alignment of the bearings in

the vertical plane, while differences between the measurements in the horizontal positions indicate out-of-alignment in the horizontal plane. Very roughly the crank-web difference is a measure of the amount of out-of-alignment, *e.g.* 2 thousandths crank-web difference indicates an out-of-alignment of about 2 thousandths.

The best instrument to use for this purpose is the Dial Test Indicator. It is possible to measure crank-web differences with a point gauge and feelers, but this method is less accurate and requires considerable skill in taking readings in a confined space. It is difficult also for two individuals to take readings which will in any way agree.

There are several important points which must be observed when taking crank-web readings :—

(*a*) The journal must be true. This should be checked first with the dial test indicator.

(*b*) The engine should be allowed to cool down before taking any measurements, for with a shaft warm, it has expanded longitudinally and unreliable readings may be obtained.

(*c*) Before taking measurements, and after the engine has cooled down, it should be barred round by hand two or three times. This relieves any end strain in the crankshaft due to the flywheel at one end and the thrust bearing at the other. Neglect to do this will give false readings.

(*d*) The measurements should be taken at about $\frac{5}{8}$ in. in from the edge of the crank web.

(*e*) A mark should be made on the inside surface of the web so that measurements are made roughly between the same points, through the cycle. This ensures that there are no inaccuracies due to local unevenness.

It has been suggested that the web differences as measured above, do not give the conditions obtaining when the engine is running, since the web openings may be greater due to the thrust of the piston. This is true ; but it has been found in practice to be a fairly good indication of the condition of the bearings (but *see* Sec. **106**, para. 4).

The point arises as to how far crank-web differences may be allowed to go before taking action. A prominent engine-builder gives the following limits of allowable differences :—

Size of engine	*H.P.*	*H.P.*	*H.P.*
B.H.P. per cylinder	25–60	60–120	120
Allowable difference	0·002 in.	0·003 in.	0·004 in.

Crank-web measurements should be taken regularly every 750 *hours*, or oftener if bearing wear is increasing rapidly.

6. **Alignment of the driven machine.**—Where an engine is direct-coupled to a 2-bearing generator or other machine, the coupling should be disconnected every 1,500 *hours*, to check the alignment. The weight of the flywheel should be taken so that the engine coupling face is exactly vertical to the planed facings on the bedplate. The clearance can then be measured with feelers between the engine coupling face and the generator coupling face. If the machines are in alignment this clearance will be the same all round.

7. **Piston-rod and piston.**—The piston should be drawn after every 3,000 *hours'* running and thoroughly cleaned. The gudgeon pin should be withdrawn and checked for wear.

Careful examination of connecting-rod bolts, both big end and small end, for signs of hammering, is most essential. These in course of time crystallize and lose their ductility, especially when stressed in the neighbourhood of the elastic limit of the material.

Certain engine-builders mark off a definite length upon their connecting-rod bolts. This is done by filing a flat on one of the threads and putting a centre dot on the flat. The distance is measured from the underside of the head to the dot. Any stretch can be thus easily detected. A longitudinal line is also scribed on the bolt, preferably placed to pass through the dot. This line will at once show up any twist due to overtightening.

Any bolt showing the slightest sign of stretch or twist should be replaced by a new one at once. It is possible to extend the life of a defective bolt by heat treatment, but such treatment to be successful requires exact knowledge of the composition of the bolt and very careful control of the process, and is not possible with apparatus normally available. The practice of taking out bolts and resting them for a period is useless, as no improvement of the bolt occurs during resting.

The life of a bolt varies enormously from 3,000 to 35,000 hours. It is suggested that bolts should be replaced every 3,000 *hours*. All the bolts in any line in which piston seizure has taken place should be replaced at once, as they will undoubtedly have been overstressed.

It is useful to stamp on the head of each bolt, the date on which it was taken into use, and if the hours of running are not recorded, bolts should be replaced after two years' service.

When replacing bolts after examination the greatest care should be taken not to overstress them by overtightening. Correct spanners should be used to avoid this.

8. **Water-spaces.**—In an oil engine in good running order approximately 30 per cent. of the heat units of the fuel oil

pass away through the water-jackets. The importance of keeping the surfaces to be cooled free from deposits such as carbonate of lime, sludge, vegetable matter and other refuse, will be readily appreciated. Neglect of this important point produces serious overheating and causes :—

(*a*) Loss of power through distorted valves and seats.
(*b*) Seized pistons through the destruction of the oil film between piston and liner.
(*c*) Cracked cylinder covers and pistons.

No definite period for the washing and scraping out of water-spaces can be laid down, as so much depends upon the purity of the water used for cooling purposes. An inspection period must therefore be decided upon to suit each station. An average figure would be in the neighbourhood of 1,000 *hours*.

9. **Drawing liners.**—It is not possible completely to clean all water-spaces merely by washing or mucking out. Chipping may be required and it will be necessary to withdraw liners to do this. The period after which this should be done is again a matter for local decision. For good water a usual figure is 3,000–4,000 *hours*.

With a very hard water, liners will have to be drawn frequently to chip off the offending scale. In such cases it may prove economical to instal a water-softening plant for the cooling water.

Incidentally, scale formation takes place most rapidly if the engine is shut down and circulating water shut off, thereby raising the temperature of the water. Circulating water should therefore be allowed to run for about 15 minutes after shutting down, an auxiliary pump or elevated tank being installed for the purpose.

Micrometer readings of the internal diameter of liners at the top, bottom, and mid-way positions, both longitudinally and transversely across the engine, will, of course, be taken when the liner is put back. Such readings should also be taken whenever the piston is drawn. Signs of internal collapsing of the liner usually indicate that the liner is not free to expand longitudinally owing to its free end being held by accumulations of rust and scale.

10. **Fuel pump.**—This requires very little attention beyond cleaning out the sump chamber every 750 *hours*, and the draining off of the water before starting up and occasionally during running. This is particularly necessary where heavy fuel-oils are used (and especially where storage capacity is small), as such oils hold water in suspension.

The valves should be ground in every 3,000 *hours* in the same way as has been recommended for the fuel valve.

Compressor

The following remarks, of course, only refer to the blast air-injection type Diesel.

11. **Compressor piston.**—The compressor piston should be drawn and thoroughly cleaned after 1,500 *hours' running*. The compressor cylinder should be examined for signs of over-lubrication. Too much oil will cause carbonization of pistons and valves and wear and corrosion of the intercooler tubes. At the same time micrometer readings of the bore should be taken and checked for wear.

The liners and water-spaces should be treated on the same general principles as those laid down in paras. 8 and 9 for the main cylinders.

12. **Compressor valves.**—These should be cleaned and ground in according to the following table :—

Two-stage compressors ..	H.P.	valves	300 hours.
	L.P.	,,	500 ,,
Three-stage compressors .	H.P.	,,	500
	I.P.	,,	1,000
	L.P.	,,	1,000

Compressor valves are usually of the disc type, and the best way to grind in these and their seats is to rub them up to a common surface on a piece of plate-glass or metal with fine carborundum paste and finish off with metal-polish. The intercooler pressure gauge gives a very good indication of the condition of the valves.

The lift of the compressor valves should be adjusted when it exceeds by 50 per cent. the original lift given by the engine makers.

13. **Intercooler coils.**—In some engines the H.P. cooler consists of a copper coil. This is subject to a certain amount of deterioration and wastage, generally attributed to acidity produced by the presence of lubricating oil in the high-pressure air. Dust or water particles in the air will increase this wear.

These coils should be weighed periodically (every 1,500 *hours* is suggested), and when the weight has decreased to 75 per cent. of the original, then the coil should be replaced.

A method adopted by some engine-builders is to drill a hole with the point of a $\frac{1}{32}$-in. drill, to a depth of one-third of the thickness of the metal, in the portions of the coil where wear is most likely to occur. When the coil has worn away to the bottom of this hole, a pinhole is formed through which air escapes into the cooling water and an indication is given that the coil should be replaced.

In any case the coil should be scrapped after 10,000 *hours'* running.

14. **Air receivers.**—These accumulate a certain amount of water and oil in the form of an emulsion which should be blown out every 50–60 *hours'* running.

In addition to this, the blast bottle, *i.e.* the bottle supplying the blast injection-air, should be thoroughly washed out every 750 *hours* and the main bottle every 3,000 *hours*. This washing out should be done with hot soda-water; *paraffin should never be used* on account of the danger involved.

15. **Flywheel.**—It is most important that the key securing the flywheel to the shaft should be a good, tight fit. Any play here will cause hammering, eventually resulting in a cracked shaft or flywheel boss, if nothing worse. It is, therefore, as well to look to this point every 250 *hours*, for the little time required is well spent.

A loose key must be replaced if it cannot be refitted. Packing out with metal strips is fatal.

16. **Annual overhaul.**—Every set should have a thorough overhaul once a year (usually corresponding to about 3,000 *hours'* running). At this time cleaning out of the exhaust pipes and silencer pit should not be overlooked. All oil-holes in crank pins, bearings, cylinder walls, &c., should be thoroughly raked out with a piece of wire. "Flick" from cotton rags, pellets of white-metal, &c., are very liable to block oilways.

Finally, all wearing parts should be carefully gauged and the results logged. Valuable information is thus available at any time as to the condition of the engine.

17. **Spare parts.**—The following should be held:—

One fuel needle.
One pulverizer, complete with ring.
One exhaust valve, with seating.
One set of springs.
Set of piston rings for the engine cylinder and air compressor.
Set of connecting-rod bolts.

18. **Running stores.**—The following should be held:—

Asbestos mill-board or vulcanite, $\frac{1}{2}$ mm. thick, for cover packing.
Metallic packing for fuel valves. (Lead wool is suitable.)
Cotton or hemp packing for air-vessel valves.
India-rubber sheeting, $\frac{1}{16}$ inch thick, for water joints.
Hemp, emery-powder, red lead, and boiled linseed oil.

19. A monthly maintenance programme should be drawn up on the lines of Table V. The fuel valves should be attended to at least once a week.

TABLE V.—*Monthly maintenance and cleaning table for Diesel engines*

	1-cylinder engines	2-cylinder engines		3-cylinder engines		
		1st cylinder	2nd cylinder	1st cylinder	2nd cylinder	3rd cylinder
1st week.	Compressor valves. Fuel-vessel filter. Lubricating banjo-ring of crank bearing.	Compressor valves. Lubricating ring.	Exhaust valve.	Compressor valves. Fuel pump (*d*). Fuel filter.	Exhaust valve. Lubricating ring of crank bearing.	—
2nd. week.	Exhaust valve.	Exhaust valve. Fuel-pump valve. Fuel filter.	Compressor valves.	Exhaust valve.	Compressor valves.	Exhaust, starting, suction, and fuel valves.
3rd week.	Compressor valves. Fuel pump valves.	Compressor valves.	Exhaust, starting, suction, and fuel valves	Compressor valves.	Exhaust, starting, suction, and fuel valves.	Compressor valves.
4th week.	Exhaust, starting, suction, and fuel valves.	Exhaust, starting, suction, and fuel valves.	Compressor valves.	Exhaust, starting, suction, and fuel valves.	Compressor valves. Forced lubricating filter.	Exhaust valve.

NOTE.—The testing of air vessels is dealt with in Regulations for Engineer Services, Part II, para. 27a.

103. *Lay-out of solid-injection Diesel plant*

Attention is drawn to the following sections :—

73. Air filtering, page 300.
74. Cooling, page 301.
75. Silencing, page 308.
146. Engine foundations, page 546.

Typical examples of solid-injection engines have been shown in Pls. **82, 83, 84,** and **86.**

Manufacturers supply all the necessary foundation and lay-out plans and drawings, and the engine price includes, as a rule, for everything essential to the working of the engine, except the concrete foundations, fuel-storage tanks, cooling tanks and sump, and external pipe connections. These auxiliaries are usually quoted for as extras; so too are auxiliary circulating pumps and air compressors.

Pl. **87** is a dimensioned drawing of the lay-out of the engine illustrated in Pl. **83.**

An auxiliary motor-driven circulating pump is provided with a small sump in the engine room. It is preferable, however, to provide a larger sump and place it outside. Sec. **74** deals with this point. The expense fuel tank is situated so that the exhaust can be used for heating the fuel. The fuel-storage tanks must be placed outside the engine room.

An auxiliary motor-driven air compressor is provided for charging the starting air-bottles in case the pressure should be lost with the engine stationary. One such auxiliary air compressor only is sufficient in a power station, as normally the engines themselves charge the air-bottles.

Pl. **87A** shows a suggested lay-out plan for three of the engines shown in Pls. **83** and **87**, direct coupled to 75-kW. generators. Owing to the increased speeds of modern designs, however, the same size of building will comfortably accommodate three engines of the type illustrated in Pl. **84**, driving 220-kW. generators.

It will be noted that the roof and gantry spans are rather large (50 ft.). If the installation is to be a temporary or semi-permanent one, it may be cheaper to make the building longer and narrower, with the switchboard at one end and an off-loading area at the other, near the main door.

Pl. **88** is a typical lay-out for two 60-kW. solid-injection Diesel generating sets in an underground power station which has been reduced to the smallest possible dimensions.

For Bibliography, see page 688.

CHAPTER XX

OVERHAUL OF I.C. ENGINES

104. *Introduction*

1. **General.**—This chapter applies particularly to small vertical high-speed engines up to about 40 B.H.P., but in a general way it is applicable to all I.C. engines.

2. Before commencing the overhaul of an engine, study the maker's instruction handbook and sectional drawings and make quite certain that the operations involved in stripping down the engine are clearly understood.

Verify that all necessary special spanners and other tools are available. Box-spanners should always be used wherever possible. Dial micrometer gauges are indispensable, and the Ames test-bench with magnetic gauge-mount is of very great utility. Some of its uses are pointed out later.

3. Prepare overhaul inspection sheet. All measurements of journals, cylinders, &c., and the condition of all parts should be carefully logged as dismantling proceeds.

4. Clear sufficient floor-area and bench-room to accommodate the engine (except in the case of the larger and heavier engines it is better to carry out extensive overhauls in the shop and *not* on site. The practice of carrying out repairs to individual engine parts on the floor beside the engine makes it impossible to keep a tidy engine room). Prepare supports to place the engine at a convenient height and procure some wooden boxes or cupboards in which to store the parts in a regular manner as they are removed.

5. Before removing anything, clean the exterior of the engine sufficiently to verify that the different parts are *marked* to facilitate reassembly. As the dismantling proceeds, this must be carefully borne in mind and additional marks made where necessary, *e.g.* it is important that the halves of main and big-end bearings should be replaced correctly in the positions from which they were taken.

A paraffin bath or degreasing plant should be available. No cotton-waste must be used.

6. Take care not to damage parts in removal. Parts suspected of being broken must be removed with care so that pieces do not jam or score during the operation.

7. As each part is removed, it should be cleaned and carefully examined as to the advisability of its replacement or repair.

Parts which it is not considered possible or economical to repair should be put on one side and immediate action taken to obtain replacements.

8. Replace nuts and washers on their respective studs or bolts.

105. *Dismantling the engine*

1. **Before dismantling.**—(i) Study the history sheet and, if possible, run the engine on moderate load for an hour or two and note and *record* its behaviour. If indicator diagrams can be taken so much the better. Such a diagnosis will be found of great assistance in determining what adjustments and repairs are necessary. It will also afford an instructive comparison with the results obtained on the completion of the overhaul.

(ii) *Test tightness of valves.*—While the engine is warm turn it slowly by hand, when the relative compression of the cylinders can easily be felt. If the compression in one cylinder is appreciably weaker than in the others, the cause will probably be found in the improper seating of one of the valves of that cylinder due either to insufficient clearance between the valve tappet and the end of the valve stem, or to the fact that the valve itself is sticking, possibly as the result of the stem being dirty or bent.

(iii) *Testing cams and camshaft drive for wear.*—Examine for excessive wear any chains or gears used to drive the camshaft (or auxiliaries).

In the case of chains, wear in the pins leads to chain-stretch, the pitch becomes longer, and in consequence the chains ride higher on the sprocket wheels. Excessive backlash in timing-gear causes noisy running due to the pressure of the valve springs on the cams when the valves are closing. The cams themselves may be worn and also the roller cam followers, or their pins.

(*a*) Mark correct inlet and exhaust valve openings on flywheel to maker's instructions. If not known, Pl. **68** may help.

(*b*) Adjust tappet clearances to maker's instructions. If not known, the following figures may be assumed (with engine hot) :—

Side valves	$\frac{3}{1000}$-in. inlet	$\frac{4}{1000}$-in. exhaust.
Overhead valves ..	$\frac{4}{1000}$,,	$\frac{6}{1000}$,,

(*c*) Crank engine round to each valve-opening position in turn, as indicated by flywheel marking, and check the valve timing.

The point at which the valve leaves the seat can best be determined by means of the Ames magnetic gauge-mount (*see* next para.). If this apparatus is not available, a piece of tissue-paper between tappet and valve-stem will be just gripped when the valve commences to lift. (Checking timing by piston position is not an accurate method, because the critical moments occur near the end of the stroke.) If the flywheel has to be moved forward beyond the correct position before the valve lifts, wear is indicated. If the inaccuracy is due to the drive, the timing of all the valves will be retarded, and before proceeding to investigate the condition of individual cams, the flywheel must be moved forward so that the backlash in the drive is the same as when running.

Note and *record* results carefully.

(iv) *Test connecting-rod bearings for wear.*—Take off cylinder head and remove loose carbon. Put each cylinder in turn on top dead-centre and measure the combined wear of the big and small ends. This can be done most conveniently and quickly by means of the Ames magnetic dial micrometer gauge-mount (Pl. **89**, Fig. 1) and a rubber suction cup as shown in Pl. **89**, Fig. 2.

When the piston is raised by the suction cup (which has a lift of about 50 lb.) the dial micrometer indicates the movement due to wear, which should be carefully *recorded.*

In the average lorry engine, if the play measured in this way does not exceed 0·005 in., it is unnecessary to dismantle the engine on this account alone, but if a general overhaul is carried out the fault must, of course, be rectified.

(v) Carefully note and *record* any other irregularities which are detected.

2. **Dismantling** may now be proceeded with. Any other defects which become apparent during the stripping down must be carefully *recorded* as the work proceeds, and the *overhaul inspection sheet filled in.*

i. First empty oil sumps and water-jackets.
ii. *Remove small fitments.* Magneto, carburettor, gauges, thermometers, &c., which are liable to get lost or broken in lifting or in transit, should be removed *on site* and carefully packed in a separate box. Replace nuts and washers on studs and bolts.
iii. Transfer engine to workshop and remove the inlet and exhaust manifolds, oil- and water-connections and all auxiliaries.
iv. The dismantling of the main parts of the engine can now be carried out. The procedure will depend upon the size, type and construction of the engine.

AMES DIAL GAUGES

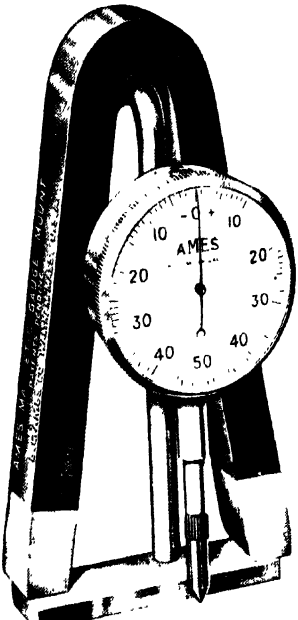


Fig 1

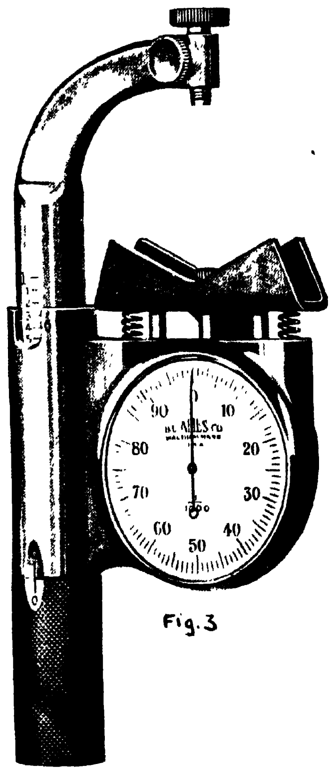


Fig. 3

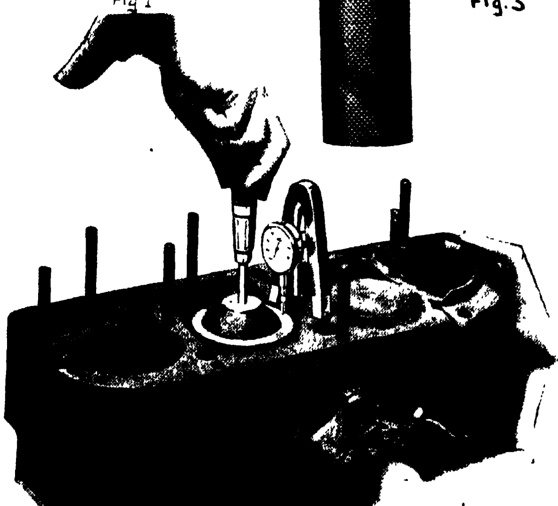


Fig 2.

The piston-rings must be carefully removed in case it may be possible to use them again.

If they are slightly gummed in their grooves, apply some paraffin and loosen them by tapping with a block of hard wood. When the rings are loose they can be taken off the piston with four thin metal strips about ½ in. wide.

106. *Principal repair operations*

1. **Straightening crankshafts.**—A bent crankshaft should be straightened by the application of a steady pressure. No heat need be applied.

Pl. **90**, Fig. 1, shows a six-throw crankshaft set up for straightening in a *Weaver* press. To check alignment, a dial test-gauge, mounted on the forcing plate of the press, is moved under the shaft and the lever arm of gauge adjusted so that it will be in contact with the underside of the shaft during one complete revolution (*see* Pl. **90**, Fig. 2). The difference between the highest and lowest readings indicates twice the amount the shaft is out of true.

To straighten the shaft :—

i. Set it hogging, *i.e.* with the curve above the axis, and apply sufficient pressure to straighten it.
ii. Remove pressure and measure the amount of spring-back, x thousandths of an inch.
iii. Apply pressure again to give a sag of x thousandths below straight.
iv. Remove pressure and measure again. Repeat if necessary.

If no special apparatus is available, a jack and strap plate may be used as shown in Pl. **90**, Fig. 3.

2. **Straightening connecting-rods.**—Small connecting-rods are easily bent through rough handling. Bends can be detected on a surface plate and straightening can be done, without heat, by the application of quite small steady forces.

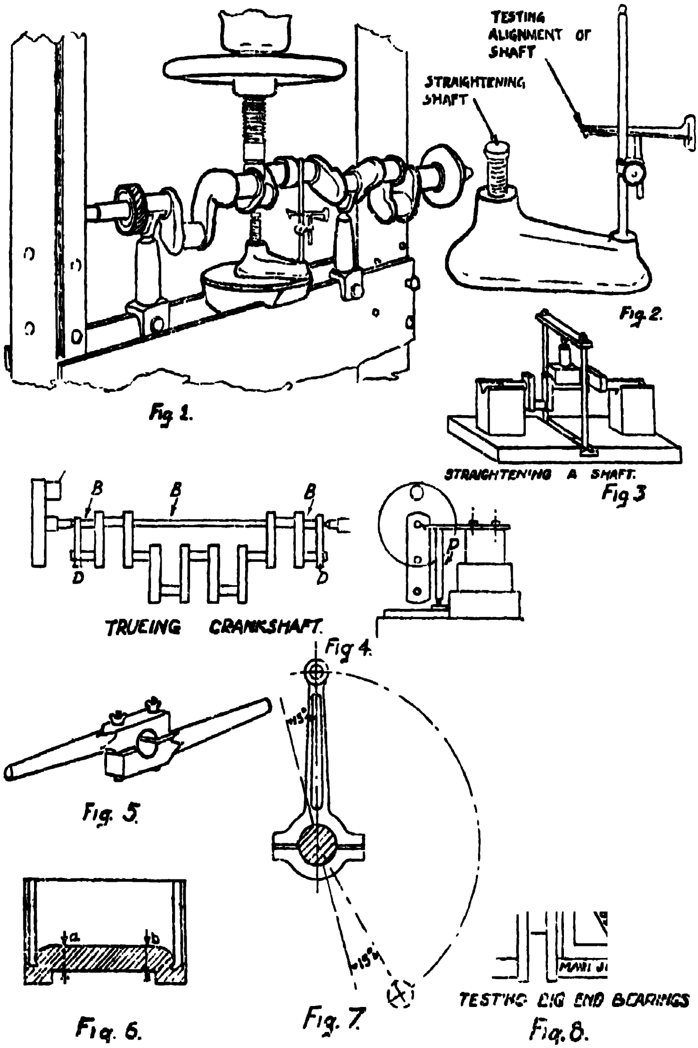
The operation is similar to that of straightening crankshafts.

An accurate final check can be made by assembling the connecting-rod on crankshaft and setting up shaft in vee-blocks on a surface plate with the shaft axis parallel to the plate. Then insert gudgeon pin in small end bush and by means of a surface gauge in conjunction with a dial indicator, check the pin.

3. **Trueing journals.**—Ovality of journals can be measured quickly by the *Ames* crankshaft gauge, illustrated in Pl. **89**, Fig. 3.

PLATE 90.

ENGINE OVERHAUL OPERATIONS



(i) *Crankshaft and big-end journals.*—If there is any appreciable wear, journals must be trued by one of the following methods :—

(*a*) By skimming in a lathe (which must be *true*) or a cylindrical grinder. The method of setting up the crankshaft for turning the big-end journals is shown in Pl. **90**, Fig. 4. Blocks, B, are placed between the webs to prevent distortion due to pressure from the lathe centres. Dummy cranks, D, are necessary for turning the crank pins, and since a long tool is necessary, light cuts should be taken and the tool supported from the slide-rest by a prop, P. If available, a *grinding attachment will do the work more accurately* and with less loss of diameter of journals than a lathe tool. Care must be taken to see that the big-end journals are turned up parallel to the crankshaft.

(*b*) By filing flats at high spots and then smoothing off the metal between the flats by lapping with emery and oil. This is a difficult operation for a skilled fitter, and is tedious if a large amount of metal has to be removed.

Care must be taken to finish off the crankshaft journals so that they are truly co-axial. Small shafts can be checked on a surface plate.

Accuracy may be checked as indicated in Pl. **22**, Fig. 2, or by a crankshaft gauge.

(*c*) In either case the finishing work may conveniently be done by lapping, using the apparatus shown in Pl. **90**, Fig, 5, lead-lined and charged with dry flour of emery. The journal must be lubricated with oil during the lapping process.

(ii) *Gudgeon pin.*—The small-end bearing usually comprises a precision-ground, hardened mild-steel pin working in a phosphor-bronze bush, solid in small sizes and split in large ones.

It is unusual to find any appreciable wear in a gudgeon pin, and if there is, it should be replaced by a new pin.

(iii) *Other small journal pins generally.*—If pins are badly worn they should be renewed. If slightly worn they may be turned up in a lathe or cylindrical grinder, but new bushes will then be necessary.

4. **Fitting bearings.**—(i) *Fitting main bearings.*—This comprises the operation of *scraping in* to fit the shaft journals and of *aligning* the bearings.

In the case of brass or bronze bearings of circular outside section, or white-metal bearings, which are carried in a cast-iron or cast-steel shell of circular section (as normally used in I.C. engines), it is not possible to correct the alignment by packing or filing, as this would spoil the fit of the bearing in the engine-bed. This is most important in the case of white-metal bearings, as any movement or flexure of the shell will almost certainly result in loosening of the white-metal lining.

The alignment and fit must therefore be obtained simultaneously by scraping the face of the bearing.

Re-metalling white-metal bearings.—When the white-metal shows signs of breaking away from the shell, the bearing should be re-metalled (*see* Sec. **30**). It may be convenient to do this before it is actually necessary, to avoid additional work on other bearings or parts. It would certainly be advisable if one bearing showed excessive wear while the others were in good condition, as it would save scraping all the good bearings down to the level of the worn one.

It must be noted that after re-metalling, a shell is generally found to have become distorted a little and it must therefore be re-bedded into the housing by careful filing.

(ii) *Aligning the crankshaft.*—This is most conveniently carried out, in the first place, *without the flywheel* (if possible) as follows :—

(*a*) *True all journals* as described above.

(*b*) *Bed the shells into their housings* to ensure good support and metal-to-metal contact everywhere. (This should be unnecessary unless the bearing has been re-metalled.)

(*c*) *Scrape the bearings to the journals.*—*See* Sec. **37**, para. **9**.

Where possible it is preferable to bore all the bearings in place in one operation (and then scrape), but the special boring machine required for this is not likely to be met in the service.

It is essential in all cases that the axis of the crankshaft shall be at right-angles to the cylinder axes.

To ensure this in a stationary engine the shaft must be aligned parallel to the surface of the engine-bed, and this should be checked as soon as the shaft is resting properly in the two end-bearings. A scribing block with dial-test indicator should be used for this purpose (after checking the diameter of the journals).

In the case of a car engine, the upper machined surface of the crankcase can generally be taken as a plane of reference, and to carry out the above test it will be necessary to turn the top half crankcase upside down and place it on a surface plate. The alignment of the other bearings is now proceeded

with, and finally the whole is re-checked with the flywheel in position.

The final fitting of the top halves of the bearings cannot be attempted until the shaft has been properly bedded and aligned in the lower halves. The top halves should at first be scraped out only as much as is necessary to enable them to be placed on the shaft. When the lower halves have been completed, the top halves should then be scraped in to the proper running clearances.

On no account is the clearance to be obtained by adjusting the nuts on the bearing.

The following remarks apply to larger engines (say) 20 H.P. per cylinder and above :—

A truly machined shaft properly bedded in without flywheel should have its weight carried equally by all the main bearings. This can readily be tested by endeavouring to turn the bearing shells in their housings. If one turns freely and the adjacent one cannot be turned easily, the inference is that the latter is carrying more weight than the former.

Making use of the fact that the shaft, on account of its shape, is by no means rigid, *web gauging* may also be used to check the alignment. (*See* Sec. **102,** para. 5.)

If the alignment is correct the distance between the crank webs should be the same for all positions of the shaft, and for erection purposes no tolerance should be permitted.

When all bearings have been properly fitted and aligned, measurements should be taken, with a micrometer gauge, of the thickness of the bottom bearings near each end (at " *a* " and " *b* ", Pl. **90**, Fig. 6), measuring from the bearing surface of the metal to the bearing surface of the shell on the engine-bed. This should be recorded for future reference, and will afford a valuable guide for future overhauls. It is usually possible to remove bearings of all but the smallest engines without dismantling the engine, and when the web-gauge test shows that bearings are wearing out of line they can be removed, micrometered, and the high ones scraped down to proper alignment one at a time, without putting the engine out of action for more than a few hours at a time.

If these records have not previously been kept, the same method may still be employed to obtain an approximate indication of the amount to scrape down the bearings, as it is unlikely that there will be any serious variation in the housings for the bearings in the engine-bed. When it is known that a good deal of metal has to be scraped off the bearing, much time may be saved, as one can then carry on scraping freely for some time before checking with the shaft.

The micrometer readings should be recorded every time the bearings are scraped in, and if possible the bearings of a new

engine should be micrometered before appreciable wear occurs.

If the bare shells are also measured when re-metalling, a record of the thickness of the white-metal lining will also be available at any future date.

Where it can be applied, gauging the main bearings gives a much more accurate check of alignment than gauging the crank webs.

(iii) *Big-end bearings.*—The above instructions apply generally, but alignment in this case means only aligning at right-angles to the axis of the connecting-rod.

Big-end bearings tend to wear oval and generally require re-scraping in after (say) 2,000 hours' running. If not too great, the wear can be taken up by reducing the thickness of the liners between the two halves of the bearing.

Assuming that the big-end journal is parallel to the crankshaft and that the connecting-rod is straight, the alignment can be checked as shown in Pl. **90,** Fig. 8. The side of the small end should follow the edge of the square throughout a complete revolution, *i.e.* in four positions 90° apart.

A running clearance of about 0·0005 in. per inch diameter should be allowed in big-end bearings. The fit can be roughly checked as in Pl. **90,** Fig. 7. The rod should just swing under its own weight through the angle shown.

(iv) *Re-bushing holes.*

(*a*) *Small ends of connecting-rods.*—If the bush is worn appreciably a new one must be made. *See* Sec. **43,** para. 17. It is important that the bush should be turned outside and bored and reamed at the same setting in the lathe.

The gudgeon pin must be truly parallel with the crank pin, viewed both in the horizontal and the vertical plane. This can be checked by the aid of a surface plate, two vee blocks, two mandrels (a push fit in big and small ends of rod), a scribing block and a dial micrometer. The mandrels should be as long as is conveniently possible. A similar method is adopted for testing whether the piston pinhole is at right-angles to the piston.

These and many other operations can be carried out most accurately and expeditiously by the *Weaver motor service press* (supplied by George Hatch), which is an invaluable machine in a small engine repair shop.

A running clearance of about 0·0005 in. per 1 inch diameter of pin should be allowed.

(*b*) *Other bushed holes.*—For well-lubricated bearings, such as in crankcases and gear boxes of motor vehicles, the bore of a bush should normally be 1/1,000 of the diameter larger than the pin which is to revolve in it. In more exposed and

less efficiently lubricated positions, up to 2/1,000 of the diameter may be allowed. The outside of a bush should be normally the same size as the hole it is to fit, or only very slightly smaller, so that it will draw home firmly. Bushes should be of hard phosphor-bronze if the pin is hardened, and of a softer bronze or white-metal if the pin is of mild steel.

(*c*) *Grinding out plain holes.*—Plain unbushed holes on rods, links, &c., should be ground out in an internal grinding machine, if available. Otherwise the hole may be lapped out with a cylindrical plug of lead or copper, using fine emery and oil.

New pins should be made, the clearance being $\frac{d}{1,000}$.

5. **Pistons and piston clearance.**—The pistons themselves seldom wear seriously.

When first fitted the piston clearance at the skirt, from x to y, is made from 0·00075 to 0·001 in. per inch diameter for cast-iron pistons, and from 0·0015 to 0·002 in. per inch diameter for aluminium alloy pistons (*see* Pl. **93**, Fig. 1). The clearance at the lands between the ring grooves and above the top ring should be greater on account of the higher local temperature. The piston is therefore tapered from y to z to give a clearance of about 0·003 in. per inch diameter above the top ring for cast-iron, and 0·004 in. per inch diameter for aluminium alloy. This clearance must not be too great as there is a tendency for the gap to get filled with carbon, which scores the cylinder.

When the cylinder wear exceeds 0·01 in. it should be re-ground and a new piston (and piston-rings) fitted.

6. **Trueing cylinders.** — Cylinders of double-acting engines wear hollow in the centre, as illustrated by the steam-engine cylinder shown in Pl. **23**, Fig. 8. Most I.C. engines are single-acting and the wear occurs at one end of the cylinder only, as indicated in Pl. **93**, Fig. 2. The ridge which forms at the end of the travel causes *knocking* and a tendency to break the upper piston-ring, and the increased clearance between piston and cylinder causes *piston slap*. The cylinder bore is measured with a cylinder gauge, preferably of the dial micrometer type as illustrated in Pl. **91**, Figs. 1 and 2.

(i) Cylinders badly worn are best treated by boring them afresh in a lathe, boring machine, or internal grinding machine. (*See* Sec. **47**, para. 7.)

(ii) *Honing.*—Honing is an internal finish grinding process which is being used successfully for cylinders from $\frac{3}{8}$ in. to 72 in. in diameter, and for gun-barrels 60 ft. in length.

It is particularly applicable, however, to small cylinders up to about 5 in. in diameter, *e.g.* motor-car cylinders and

hydraulic cylinders; the advantages being extreme accuracy and smoothness of finish combined with simplicity of method and speed of operation.

Mechanically the process of *honing* consists in revolving abrasive stones in the cylinder bore, at the same time giving them a reciprocating motion. The stones are mounted in a holder resembling an adjustable reamer. The rate of rotation is generally such as to give a surface speed of about 200 to 250 ft. per minute, and the number of double reciprocations is commonly about one-third the number of revolutions.

To avoid a " bell " effect at top or bottom, or a " barrel " effect in the centre, the reciprocating strokes should be arranged to allow the stones to project about $\frac{3}{8}$ in. above and $\frac{3}{8}$ in. below the cylinder bore on every stroke. Under no circumstances should the hone be rotated after the stones are half-way out of the cylinder. During the process of honing, the tool must be flooded with copious quantities of coolant.

A cylinder gauge should be used frequently as the work proceeds.

A typical honing machine for motor-car cylinders is illustrated in Pl. **92**, Figs. 2 and 3. The six abrasive stones can be expanded to the exact size required by means of a mechanism in the spindle provided with a micrometer indicating ring.

The stones are rotated in the cylinder bore by means of either a vertical drilling machine or a portable electric drill.

Allowance for honing.—The allowance for honing depends upon the degree of finish after machining. For bored cylinders the allowance is usually two- or three-thousandths, irrespective of size. This may be reduced if the bores have been reamed or internally ground.

It is seldom practicable, however, to use the honing machine for removing ten-thousandths or more from worn cylinders and dispense with the boring operation. There is not usually a sufficient unworn parallel length of cylinder to ensure that the machine is co-axial with the cylinder.

Carborundum stones are used for cast-iron with a coolant of paraffin, and *aloxite* stones for steel liners, with water as coolant.

(iii) *Cylinders and liners.*—In modern practice cast-iron liners are used extensively. On motor vehicles it is usually necessary to re-grind the liners after 30,000 to 40,000 miles running (when the wear is probably about ten-thousandths of an inch) and fit new pistons. After another 30,000 to 40,000 miles the liners are scrapped.

Hardened steel liners about 1 mm. (0·04 in.) thick are also used to some extent. When fitted into worn cylinders it is frequently possible to use the old pistons again. The

ENGINE OVERHAUL OPERATIONS

PLATE 91

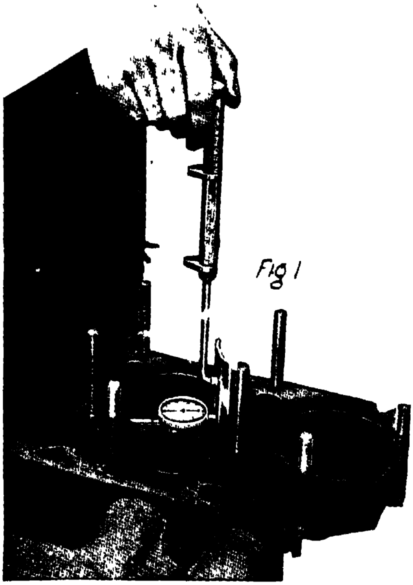


Fig 1

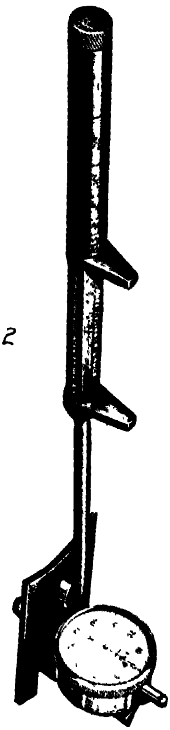


Fig 2

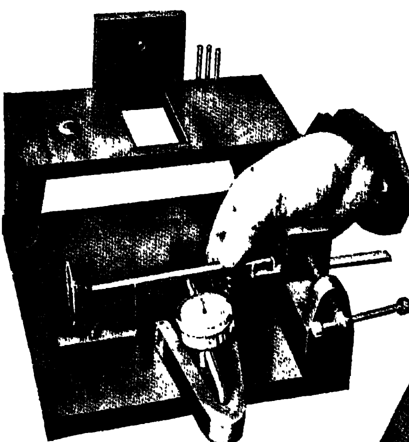


Fig 3.

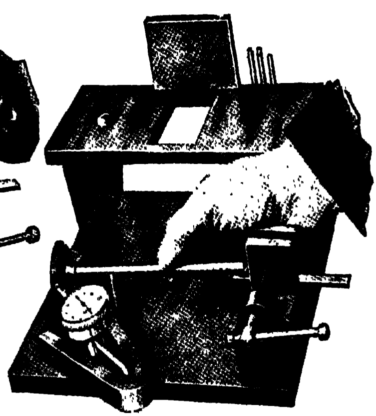


Fig 4

PLATE 92.

BLACK AND DECKER VALVE REFACER

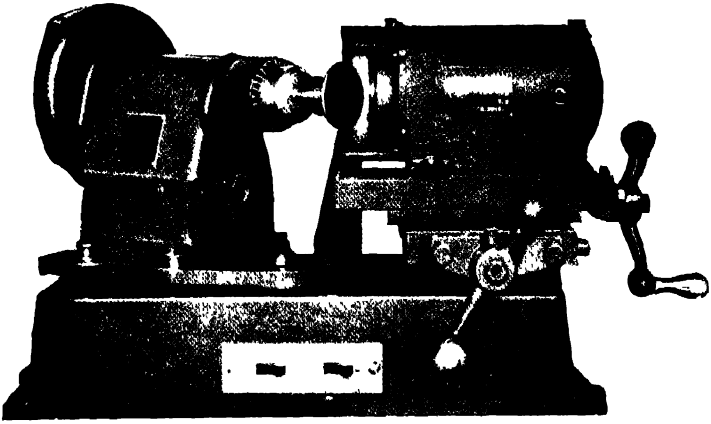


Fig. 1.

HUTTO CYLINDER GRINDER

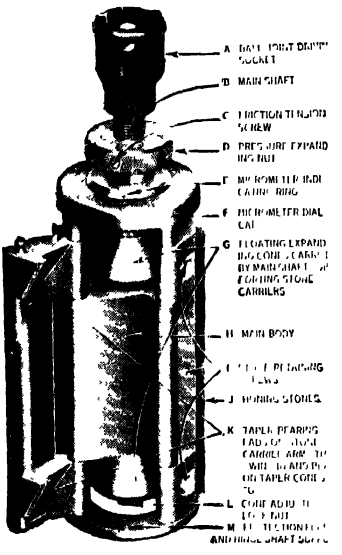


Fig. 2.

This stone is bridged by these two stones. It cannot go into the groove due to the positive set. No spring construction of the Hutto Grinder.

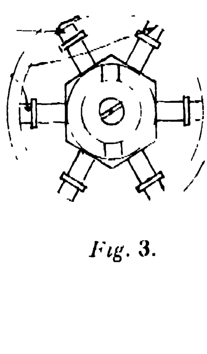


Fig. 3.

[*Permission of Messrs. George Hatch.*]

rate of wear with these hardened steel liners is extremely small, but their fitting is rather a special job.

7. **Piston-rings.**—It is in most cases preferable to obtain new piston-rings from the engine manufacturers or from firms who specialize in this component.

If circumstances make it necessary to undertake the manufacture of piston-rings locally for a variety of engines, it is advisable to keep in store a range of soft cast-iron hollow cylinders with diameters of, say, 5-in. external and 3-in. internal, 6-in. external and 4½-in. internal, &c., from which a large range of different-sized rings can be turned up.

A suitable grey cast-iron has the following analysis: carbon 3·5 per cent., silicon 2 per cent., manganese 0·7 per cent., phosphorus 0·6 per cent., and sulphur 0·05 per cent.

The operation is as follows (*see* Pl. **93**, Fig. **3**, and B.S. Specifications 5,003 and 5,023): Ring should first be turned up to outside diameter $d_1 = 1{\cdot}04d$, where d = engine cylinder diameter. The breadth b should be made equal to the width of the piston groove, and the thickness t equal to from $\frac{d}{30}$ to $\frac{d}{30} + 0{\cdot}008$. Then a gap is cut in the ring equal to $3\frac{1}{2}t$ at an angle of 45° (unless the ring is to be pinned, in which case a stepped gap is required). The ring, when compressed, then obviously assumes an oval form. It should therefore be clamped on a mandrel with the ends of the gap in contact and ground circular to diameter d. The ring must then be fitted into the cylinder at the *working section* and the ends filed to leave a gap, when in position, of $0{\cdot}002d$. The figure of $0{\cdot}001d$, which has been worked to in the past, is insufficient, and too small a gap has led to numerous cases of broken rings or excessive cylinder wear.

The ring must then be fitted to the piston-ring slots with a vertical clearance of from 0·001 in. to 0·002 in. to allow for expansion. A convenient method of doing this is to rub the ring down on emery-cloth on a flat surface. If the vertical clearance is too great the lubricating-oil consumption will be excessive, as the movement of the ring from one side of the groove to the other has a pumping effect.

The ring is now ready for putting on the piston.

Special piston-rings.—In service, the piston-rings and cylinder wall are continually wearing away, and it is common experience to find that, as time goes on, the engine loses power due to gases blowing past the rings and the lubricating-oil consumption increases. This is not only expensive as regards cost of petrol and oil but it renders more frequent decarbonizing necessary, and in most cases it is the excessive consumption

of lubricating oil which determines the necessity for re-grinding the cylinders.

In this connection attention is drawn to the *Wellworthy Simplex* piston-ring illustrated in Pl. **93**, Figs. 4 and 5. The ring has a double row of slots in it, and this enables it to be fitted into the piston groove in slight vertical compression, thus ensuring a close fit in the groove. This enables the ring to conserve the oil which enters through the slots, thus forming an oil cushion which assists in maintaining the correct lubrication of the ring itself but prevents the pumping of oil past the piston-head. The ring is given no radial tension, as in the ordinary types of ring, but is held against the cylinder bore by a wavy spring fitted behind the ring. This enables the ring to adapt itself to large irregularity and ovality of the cylinder bore. The ring groove must be deepened to accommodate this ring, and it costs three or more times as much as the orthodox type, but its fitting may save a re-bore.

Replacing old rings.—If old rings are used again take care to put them back the same way up in their own grooves.

8. **Trueing mushroom valves and seatings.**—(i) The wear and straightness of valve stems and the squareness of valve faces can be tested on the Ames test bench as illustrated in Pl. **91**, Figs. 3 and 4.

(ii) If not badly worn, the valves and their seatings can be reconditioned by grinding in with oil and emery or carborundum powder (special valve-grinding compounds can be obtained). The head of the valve is usually slotted to take a screwdriver and the operation is simplified by the use of a hand brace and a screwdriver bit. Only a very slight pressure is required, and the valve should be reciprocated through some 30° or so a few times, then raised from its seat (a light spring under the valve will facilitate this), turned into a new position and the process repeated. The valve must not be rotated, or grooves will be formed. The seatings can be finally tested by pencil-marks. Such marks should be removed by placing the valve in its seating and pressing it down while rotating it through an angle of about 10°.

(iii) If valves and their seatings are grooved or badly pitted, the operation of grinding-in by hand is laborious and not always satisfactory. Valves may be ground or turned true in a lathe, as follows :—

(*a*) The valve must be truly centred. If the original centre is present in the valve-head, this presents no difficulty. The tail can be held in a self-centring chuck, and the head supported by the tailstock centre.

PLATE 93.

ENGINE OVERHAUL OPERATIONS.

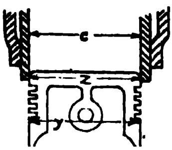


Fig.1

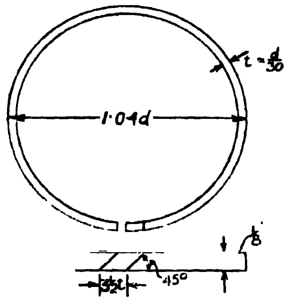
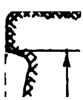


Fig.3.



'RAVEL-

3

Demonstrating the Simplex expansion in the groove. A plain ring would fall out

Fig. 4.

CYLINDER

5

2

SEAT REAMER

Fig.5.

Fig.2.

Fig. 6.

If the original centre is not present, the stem should be gripped near the head in an independent jaw-chuck, or a self-centring chuck, if an accurate one is available. The spindle of the valve must be set to run true. The outside of the head is not a sufficient guide in centring.

(*b*) The face of the valve must then be ground or turned down sufficiently to obtain a cut everywhere, leaving a true cone surface at the correct angle, which is generally 45° to the axis. This angle may be obtained by setting the hand-slide of the compound slide-rest.

Grinding is preferable to turning, since it stresses the valve less and ensures a cut. The surface of the valve is often glazed and heavily carbonized, so that a turning tool will not bite unless a fairly heavy cut is taken.

(iv) Seatings should be trued by means of a valve seater or trueing reamer of the correct angle, provided with a long stem to fit the valve guide, Pl. **93**, Fig. 6. Unless so guided and centred, the reamer will do more harm than good, since the accuracy of the seating will be entirely destroyed if the reamer is at all askew or out of line.

(v) After trueing, the valve should be ground-in as explained in (ii) above. All chips and abrasive must be carefully removed from the valve, seating, pocket, and valve-stem guide.

(vi) Special valve-grinding machines are obtainable for trueing both valves and seatings and their expense is justified if much valve grinding is done. Pl. **92**, Fig. 1, shows a Black and Decker valve-grinding machine, with electric motor. The valve is ground to the correct angle in the machine, and the seating is trued by means of a grinding stone carried on a spindle which fits the valve guide, and is rotated by means of a small electric motor. The stones are trued, when necessary, in the valve-grinding machine, thus ensuring that they match the valves exactly.

Valves ground by this method require little further grinding-in on their seatings.

9. **Welding repairs.**—(*See* Chap. VII.) Cracked or smashed cylinder blocks can be effectively repaired by electric or oxy-acetylene welding, even when the bores are damaged, if facilities exist for re-boring.

Valve seats may also be built up by either of these processes.

Aluminium-alloy crankcases can be repaired by oxy-acetylene welding only.

10. **Surface grinding.**—The principal application of this is the re-surfacing of cylinder blocks and heads. Very often an engine develops a water-leak into the cylinders which is

found to be due to the block or head having warped so that the gasket no longer makes a sound joint, in which case the obvious remedy is to have one or both re-surfaced.

Surface grinding is also largely used for finishing welding repairs.

11. **Miscellaneous jobs.**—Among the small jobs which should be done while the engine is dismantled are the following:—

i. Thoroughly clean out the crankcase with paraffin. Clean all filters and wash out all oil passages.
ii. Clean silencer and exhaust manifold, ports and pipes.
iii. Clean out water-spaces and pipes. If there is much hard lime deposit it may be necessary to fill with dilute hydrochloric acid (1 part commercial acid to 3 parts water by weight) and allow to soak for 12 hours. Then empty and wash out thoroughly with a solution of common soda in water (1 part soda to 20 parts water by weight).
iv. Clean and adjust the magneto.
v. Clean the carburettor. Grind-in the needle valve if necessary and repair the float if punctured.
vi. Renew all joints and joint-making washers.

107. *Reassembly and testing*

1. **Reassembly.**—The following points merit special attention:—

i. Scrupulous care must be taken to remove any abrasive that may have been used on the parts. Wash and re-wash them in clean paraffin and use clean rags, not waste, to dry. Use plenty of paraffin, it is not being wasted if it saves the life of an engine.
ii. Record measurements of each of the principal parts on overhaul inspection sheet, as it is replaced.
iii. It is important to verify that the axes of the cylinder are vertical and at right-angles to the crankshaft axis. It is unusual to find any appreciable error, but if there is, the crankshaft must be re-bedded.

   It may be assumed that there was no inaccuracy when the engine was new, and in the absence of evidence to the contrary it may be taken that the top machined joint surface of the crankcase was used as the plane of reference. Also it may be assumed that the top and bottom surfaces of the cylinder block were originally parallel.
iv. As each part is replaced, crank engine round and see that the part functions freely.
v. When the crankshaft has been finally bedded down, the alignment of the outer bearing (if fitted) with

flywheel and of any direct-coupled machinery will require attention. *See* Sec. **146.**

vi. The compression may also require adjustment if the crankshaft has been lowered appreciably. (The compression may be increased by grinding a little off the cylinder head or reduced by using a thicker gasket in the joint between the cylinder head and block. This is hardly ever necessary with small engines.)

It may also be necessary to adjust the gears driving camshaft, governor, &c., to enable them to mesh properly, and possibly the camshaft bearings.

No hard-and-fast rule can be given for this nor for chain replacement. It is advisable usually to replace sprockets at the same time as chains. In replacing spring links on roller chains, the closed end of the spring clip should always lead on to a sprocket. Adjust chain tensions so that in the tightest parts the chain feels just slack, not taut or springy. Tight chains are very noisy and wear rapidly.

vii. The piston-rings should be put on with the gaps staggered.

viii. When replacing the ground-in valves, the tappet clearances should be set 3- to 4-thousandths greater than the maker's values, partly because these values are given for the engine when *hot* and partly to allow for the bedding down of the valve surfaces under working conditions. At the first opportunity, under running conditions when the engine is hot, the clearances should be checked and adjusted to from 1- to 2-thousandths greater than the maker's values.

After running for 20–30 hours, the valve clearances should be again checked and re-set if necessary. Allowance should be made for the fact that the clearance is usually reduced by about one-thousandth by the locking operation.

ix. Before attempting to run the engine make sure that all nuts and lock-nuts are tight, and split-pins fitted.

2. **Testing.**—(i) If possible, motor the engine from a separate source of power, first at about half speed for half an hour or so and then at full speed for a similar period, to run in the bearings. If no overheating or other irregularity occurs, note the power input (if an electric motor is used).

In the case of an electric generating set, the generator can be used to motor the engine.

(ii) Now run the engine under its own power for a period on light load, and finally for several hours on full load, and record principal results on overhaul inspection sheet (*see* Sec. **144**).

For Bibliography, see page **689**.

CHAPTER XXI

STEAM BOILERS

108. *Elementary properties of steam*

1. **Effect of heating water.—**

i. When 1 lb. of water is heated, every B.Th.U. of heat which passes into it has the effect of raising its temperature by approximately 1° F. (exactly 1° F. at 60° F.). This is true for water at low and atmospheric pressures as long as it all remains a liquid. Thus, 1 lb. of water open to the air at sea level will require 180 B.Th.U. of heat to raise its temperature from freezing point to boiling point (32° F. to 212° F.). Normal atmospheric pressure = 14·7 lb. per square in.

ii. When the boiling point is reached, a further and comparatively large quantity of heat is required to turn the water into steam, and the addition of such heat has no effect on the temperature. In the case taken, 970 B.Th.U. are required to turn the 1 lb. of water at 212° F. into steam at the same temperature. If only 500 B.Th.U. were added—then only 500/970 lb. of steam would be formed.

iii. If, after complete evaporation of the lb. of water more heat were added to the steam formed, its temperature would rise. The amount of heat required for every degree rise, *i.e.* the *specific heat*, is not always the same, depending on whether the steam is confined in fixed volume or subjected to a constant pressure.

iv. Steam at its temperature of formation (212° F. in the case we have taken), or any steam in contact with water, is spoken of as *Saturated steam.* Steam above the temperature of formation is called *Superheated steam.*

v. When superheated steam is cooled, *i.e.* heat extracted from it, it eventually comes back to its original state as water, the order of events being the exact reverse of that outlined in i., ii., iii., above, the quantities of heat being exactly the same for the reverse process.

2. Steam terms.—

i. *Water heat* (sometimes called sensible heat).—The heat required to raise the temperature of 1 lb. of water from 32° F. to the boiling point is called the *Total heat* of water.

ii. *Latent heat.*—The heat required to evaporate 1 lb. of water when boiling point has been reached is called the *Latent heat of steam.*

iii. *Total heat of saturated steam.*—This is the heat content of 1 lb. of saturated steam (measured from 32° F.). It is the sum of the water heat and the latent heat.

iv. *Total heat of superheated steam.*—This is the total heat of saturated steam at the particular pressure plus the heat required to superheat the steam to the particular temperature.

E.g. suppose $p = 200$ lb./sq. in. gauge and $T = 600°$ F. The temp. of saturated steam at 200 lb./sq. in. is 388° F. (Table **W.**)

Therefore, there are $600 - 388 = 212$ degrees of superheat, and the total heat of the superheated steam $= 1207 + 0{\cdot}48(212) = 1309$ B.Th.U. (0·48 is the specific heat of steam at constant pressure).

3. Boiling point of water and steam tables.—

i. The boiling point of water varies with the pressure to which the water is subjected. In the case of water heated in the open air at sea level the boiling point is 212° F., but if the water is contained in a closed vessel such as a boiler, where the pressure on the water surface is, say, 100 lb. per square inch above normal atmospheric pressure (14·7 lb. per square inch absolute), the boiling point will no longer be 212° F., but 338° F. Thus more water heat will be contained in the water at its higher boiling point. When water boils at 338° F., the latent heat required to evaporate it is not the same as it was at 212° F., and atmospheric pressure; thus the total heat of the saturated steam at 338° F. will be different for this additional reason.

ii. Table **W**, known as a *saturated steam table,* shows the various pressures and boiling points which correspond, also the latent heats, total heats, and steam volumes. All the figures concern 1 lb. of water or steam, and the temperature of 32° F. is taken as the arbitrary starting point from which all quantities of heat are measured.

TABLE W.—*Saturated steam table*

(Based on Callender's revised steam tables, 1931. Note that the Mollier diagram, Pl. **110**, has been drawn from older steam tables in which slightly smaller values were given for the Total Heat.)

Absolute pressure lbs. per sq. inch.	Temperature of boiling point, degrees F.	Sensible heat of the liquid from 32° F. B.Th.U. per lb. (h)	Latent heat, B.Th.U. per lb. (L)	Total heat of the steam from 32° F. B.Th.U. per lb. (H)	Cubic feet of steam per lb.
0·5	79·5	47·4	1045	1092	650·5
1·0	101·7	69·6	1032	1102	333·1
2·0	126·1	93·9	1020	1114	173·5
3·0	141·5	109·3	1012	1121	118·6
4·0	153·0	120·8	1005	1126	90·5
5·0	162·3	130·1	1000	1130	73·4
14·7	212·0	180·0	970	1151	26·8
20·0	228·0	196·1	961	1157	20·1
25·0	240·1	208·4	954	1162	16·29
30·0	250·3	218·7	947	1166	13·74
40·0	267·2	236·0	936	1172	10·50
60·0	292·6	262·0	918	1180	7·18
80·0	312·0	282·0	904	1187	5·49
100·0	327·7	298·0	893	1191	4·45
115·0	338·0	309·0	885	1194	3·90
125·0	344·2	316·0	880	1196	3·61
135·0	350·1	322·0	875	1197	3·36
165·0	366·0	339·0	863	1202	2·78
215·0	388·0	362·0	845	1207	2·167
245·0	399·0	373·0	836	1209	1·916
265·0	406·0	382·0	829	1211	1·780
315·0	422·0	399·0	815	1214	1·511
365·0	436·0	415·0	802	1217	1·315
415·0	449·0	429·0	790	1219	1·165
3650·0	717·0	846·0	0	846	0·0413

In the absence of steam tables a close approximation to the total heat of saturated steam is given by $H = (1092 + 0{\cdot}3T)$ B.Th.U. T being temperature in degrees Faht.

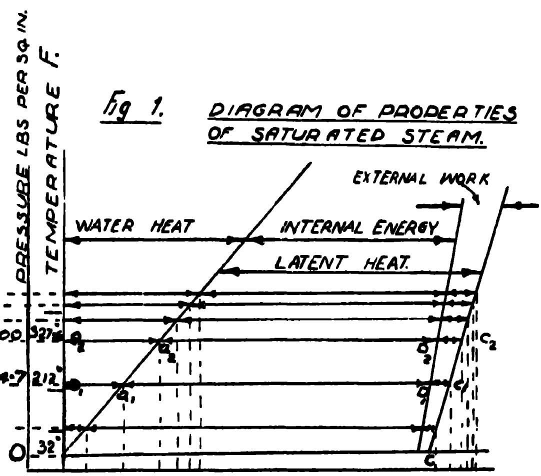
The latent heat units which are added to the water during the change into steam are absorbed in two ways.

(*a*) *External work.*—This represents the work done in pushing away the atmosphere or piston which is taking up the space required for the steam being generated. It is readily calculated in foot-pounds from the product of the total *force* overcome and the *distance* through which it is overcome.

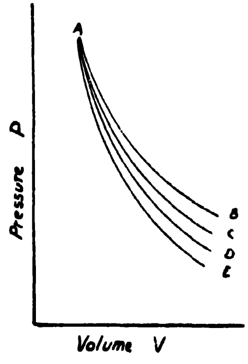
PLATE 94.

PROPERTIES OF STEAM

Fig 1. DIAGRAM OF PROPERTIES OF SATURATED STEAM.



Comparison of Expansion Curves for Steam.



AB = hyperbolic expansion PV = constant.

AC = actual expansion in an engine cylinder.

AD = dry saturated steam curve $PV^{17/16}$ = constant.

AE = adiabatic expansion from dry saturated steam $P.V.^{1.135}$ = constant.

The value of the external work done is equal to $\frac{P}{778} \times (V_s - V_w)$ B.Th.U., in which P = *absolute* pressure of steam in lb./sq. in., V_s = volume of steam, and V_w is the original volume of the water.

Absolute pressure is equal to gauge pressure plus atmospheric pressure (14·7 lb./sq. in.).

Absolute temperature is equal to temperature in degrees Fahrenheit plus 459.

(*b*) *Internal energy.* This is found by subtracting the external work from the total latent heat.

Pl. 94, Fig. 1, shows the general proportions between water heat, latent heat, and total heat for low pressures.

109. *Boiler principles*

1. **Object.**—The object of a steam boiler is to evaporate hot water into steam at a high pressure. Therefore, every effort should be made to supply the boiler with water already heated so that its work is almost entirely confined to evaporation.

2. **Heating area.**—A boiler should be so arranged that as large an area as possible is exposed to the hot gases from the grate, while water is in contact on the other side with every portion of metal so exposed, to prevent overheating of the metal.

3. **Materials.**—The material of the boiler should be of the highest conductivity consistent with reasonable strength, price and durability. Thus the firebox is frequently of copper (relative conductivity 74, *cf.* silver 100), tubes are often of brass (conductivity 23), and boiler shells are usually of mild steel (conductivity 12). Frequently mild steel is used throughout because it is a cheaper material and durable.

4. **Thickness of plates.**—The metal walls of a boiler should be as thin as is consistent with strength and durability. The thinner the plates, the more rapidly will heat be conducted through to the water, and the more nearly will the temperature of the metal on the fire side of the plate be kept down to that of the water. Not only will this diminish the chance of burning the metal, but the rate of transfer of heat from the hot gases to the metal is proportional to the difference in their temperatures. Therefore, if the metal is kept comparatively cool, heat is more readily transferred to it.

It is necessary, however, in practice, to allow an ample margin of safety, because plates and tubes are liable to corrosion on both sides, which weakens them. In practice, new boiler plates are made to provide a factor of safety of six.

5. **Water circulation.**—It is important that water inside a boiler should circulate freely, naturally, and as rapidly as possible.

When heat is transferred to water in contact with metal, the steam evolved is inclined to adhere to the metal and form a non-conducting layer between the water and the metal. In consequence, the transfer of heat from the metal to the water is slowed down, and heat accumulates to such an extent in the metal, that it may be softened and so weakened as to collapse under the boiler pressure.

If there is enough movement in the water to remove the steam film before the metal has been damaged, it will yet have gained enough heat to cause a violent burst of steam when the water touches it again. This produces a characteristic bumping sound, which is a danger signal, indicating that damage is probably occurring, and that an explosion may follow unless some action is taken to improve the circulation.

When water in contact with metal is evaporated, any substance in solution or suspension in the water is often left as a scale on the surface of the metal ; this acts as an insulator, slowing down the heat transference, and so causing a decrease in the efficiency of the boiler, and at the same time causing a danger of overheating the metal.

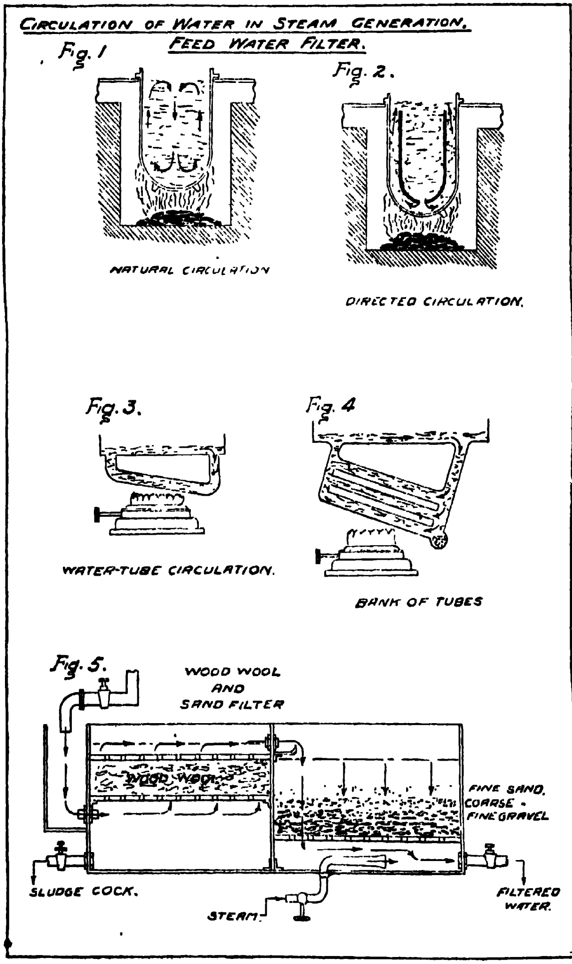
A rapid circulation of water sweeps away steam as soon as it is formed, and also tends to sweep away the solid matter which would otherwise form scale.

Streams of circulation are shown on Pl. **95**, Fig. 1. By fitting into the cauldron a short piece of wide pipe domed at the end, as shown on Pl. **95**, Fig. 2, the up- and down-streams can be kept apart, and the rate of circulation increased. A still better circulation can be obtained by fitting the vessel with a bent tube, as shown on Pl. **95**, Fig. 3.

6. **Economizer principle.**—The air rising from the fire is still very hot after it has passed the tube, and if another tube were placed above the first it would also be heated, but more slowly than the first.

The boiler shown on Pl. **95**, Fig. 4, utilizes this fact to heat water in several U-tubes, one above another. If a second vessel containing cold water were placed above, and whenever hot water was drawn from the lower one, it were filled up from the upper one, more water could be heated without increasing the size of the fire. Such an auxiliary tube corresponds to an economizer applied to the boiler of a steam engine.

PLATE 95.


CIRCULATION OF WATER IN STEAM GENERATION.
FEED WATER FILTER.
Fig. 1
Fig. 2.
NATURAL CIRCULATION
DIRECTED CIRCULATION.
Fig. 3.
Fig. 4
WATER-TUBE CIRCULATION.
BANK OF TUBES
Fig. 5.
WOOD WOOL
AND
SAND FILTER
WOOD WOOL
FINE SAND.
COARSE + FINE GRAVEL
SLUDGE COCK.
STEAM
FILTERED WATER.

7. Soot and tar deposit.—If flame, or in other words, burning coal-gas, comes in contact with any much cooler object, such as part of a boiler, the flame is quenched and carbon is deposited upon the metal as soot. Moreover, the quenched gas contains tarry vapour, some of which condenses upon the metal.

Careless firing invariably results in the forming of a coat of tar and soot upon the plates or tubes of a boiler. Even with careful firing, a small deposit may occur.

Soot is a very slow conductor of heat. A coat of soot upon the metal greatly diminishes the rate of transfer of heat from the gases to the metal. This is not dangerous, but greatly diminishes the efficiency of the boiler. Flues and tubes must therefore be cleaned frequently.

One-sixteenth of an inch of soot means a loss of 25 per cent. in the heat transference of the boiler tubes.

110. *Feed water*

The fact that water is clear and bright is no indication of its suitability for boiler feed.

1. **Common impurities** are :—

   i. *Organic impurities* in suspension which must be removed by filtering.

   ii. *Acids* due to the decomposition of organic matter, oil, &c. Even rain-water, which is usually very soft, may be slightly acid. The acidity should be neutralized by an alkali such as soda ash, or internal corrosion will result. Considerable protection against corrosion is also afforded by securing blocks of zinc to various parts of the boiler, in metallic contact with the boiler shell.

   iii. *Oil and grease* in suspension from pumps and steam engine condensate. This should not be allowed to enter boilers for several reasons :—

      (*a*) The oil will form a coating on the boiler plates and so retard the conduction of heat that dangerous overheating of the plates may occur and also the boiler efficiency will be reduced.

      (*b*) The oil may decompose into corrosive acids at the boiler temperature.

      (*c*) The oil may saponify and cause *foaming*.

   Oil and grease can be coagulated by the addition of newly mixed alumina ferric sulphate (crude alum) and sodium carbonate (soda ash), and can then be completely removed by filtering.

iv. *Salts* (mainly of calcium and magnesium) in solution which make the water *hard*.

When hard water is used, the soluble salts are precipitated at boiler temperatures and form a more or less hard scale or encrustation on the boiler plates. This scale is objectionable mainly because, having a low heat conductivity, it causes a large increase in the temperature of the boiler plates. With a water temperature of 380° F., the metal temperature is about 400° F. if the plates are quite clean, but with scale ⅛-inch thick the temperature of the metal may rise to 700° F. (dull red), which will lead to serious trouble. There is also a small loss in the steaming capacity and efficiency of the boiler but this is relatively unimportant.

To avoid the very frequent scaling which would otherwise be necessary with hard water, it should be treated *before* use to remove as much as possible of the scale-forming contents. The correct treatment which a particular water should be given can only be decided by chemical analysis, but the following notes may be helpful.

2. **Water-softening. Lime-soda process.**—The hardness of water is conveniently divided into two categories, viz.: *temporary hardness* and *permanent hardness*.

(i) *Temporary hardness*.—This is due mainly to the bicarbonates of calcium and magnesium and can be removed simply by boiling the water. It is, however, cheaper and more convenient to remove it chemically by adding *caustic lime* in the proportion of 1½ oz. per degree of temporary hardness per 1,000 gallons. The effect is to convert the soluble bicarbonates into carbonates, which are precipitated, being practically insoluble in water free from CO_2. The precipitates are then removed by filtration. The caustic lime (quicklime) should be stored in airtight containers and slaked immediately before use.

(ii) *Permanent hardness*.—This is due mainly to the sulphates of calcium and magnesium, which are soluble up to 300° F., but are precipitated at boiler temperatures. It is the scale formed by these precipitates which gives the most trouble in boilers, as it is relatively hard and adherent compared with the precipitates due to temporary hardness which form a more sludgy deposit, not very adherent and largely removed through the scum-cocks.

Permanent hardness may be removed by the addition of *sodium carbonate* (soda ash) in the proportion of 2½ oz. per degree of permanent hardness per 1,000 gallons.

In this case, in addition to the carbonate precipitates, a very soluble sulphate of soda is formed which will not be deposited in the boiler until the water becomes very concentrated. When the water in the boiler becomes too dense with these soluble salts there is a danger of them crystallizing out and exposing the plates to overheating, and, moreover, priming and foaming will occur. Also brass fittings, water gauges, and so on, will be attacked. *Blowing down* is therefore a very necessary daily operation to reduce the concentration as well as for removing sludge. About ½ in. to 1 in. of water, as represented by gauge glass, may be blown down daily in one operation and replaced by fresh and less dense water.

In order to minimize the troubles likely to arise from high concentration it is important not to add excessive quantities of chemicals to the feed water.

Alternatively, ordinary *washing soda* (which is carbonate of soda in the form of crystals) may be used instead of soda ash, but it is not so economical. Three times as much washing soda is required and the difference in price does not compensate for this.

Sodium carbonate also removes temporary hardness, but it is not so satisfactory for this purpose as caustic lime, which leaves precipitates only.

Caustic soda may in some cases be used to remove both temporary and permanent hardness, but its use should not be encouraged. Washing soda (or preferably soda ash) is much more suitable for ordinary purposes.

It is not usually practicable in the ordinary lime-soda process to remove the hardness entirely, and some 2 to 3 degrees nearly always remain. This is not important when the water is used for boiler feed, but it may be important for other purposes, in which case the "*Permutit*" water-softening process can be used (*see* M.M.E., Vol. VI).

3. **Estimation of the hardness of water.**—The *hardness* is measured by reference to the "*soap destroying*" power of the water and is expressed in *degrees*. One degree represents 1 part of hardening salt per 70,000 parts of water, *i.e.* 1 grain per gallon.

A standard soap solution for estimating the hardness of water comprises 13 grams of castille soap, 500 c.c. methylated spirit, and 500 c.c. distilled water. 1 c.c. of this solution will neutralize 1 degree of hardness in 70 c.c. of water.

If the water is tested before and after boiling the total hardness and permanent hardness will be determined respectively and the temporary hardness can be deduced by difference.

Ordinary tap-water from limestone areas may have a *total hardness* of 18–25 degrees.

4. **Filters.**—An effective filter for removing most of the chalk sludge and coagulated oil can be made by placing a layer, several inches thick, of wood-wool or fine wood shavings, between two iron plates perforated with small holes, Pl. **95**, Fig. 5.

A more efficient filter is a sand bed of well graded sand. A perforated plate of fine mesh is covered with fine gravel, but too coarse to pass through the plate. Upon this layer is placed a layer of coarse sand, and then one of fine sand, Pl. **95**, Fig. 5. A skin of scum forms upon the surface of the sand, and forms a very fine filter through which no solid particles can pass. When the scum becomes too thick for the passage of water, it can be effectually removed by blowing steam or air up through the sand; it will then float on the water and may be removed with a scoop, or run to waste.

Before water is passed through sand, it should be filtered through wood-wool to remove the coarser impurities.

5. **Oil separators.**—An oil separator is sometimes fitted in the exhaust main between an engine and its condenser. It normally consists of a vessel through which all the exhaust steam passes, and in which the steam is made to follow a sharply curved path, Pl. **115**, Fig. 7. Oil and water present are thrown outward by centrifugal force and collected. The oil can be filtered and used again if it is of a good keeping quality, such as pure mineral oil.

The steam can be freed of much oil in this way, and the condensate is sometimes used as feed water without further treatment. The addition of an oil filter improves matters very much, but the last traces of oil can only be removed by the alumina ferric treatment mentioned in para. 1.

6. **Evaporators and de-aerators.**—To ensure perfect purity of make-up water, it is sometimes obtained from an evaporator, which rejects all salts, and yet uses little heat for its operation. The only deleterious element then remaining in the feed water is oxygen, which is removed by a de-aerator.

7. **Water-softening plant.**—There are upon the market several types of plant in which a small quantity of each of the precipitating ingredients is automatically mixed with the water as it passes through; the precipitates are then allowed to settle, and finally the water passes through one or more filters. Before deciding on any special plant, it is necessary to ask the advice of the War Office.

111. *Shell boilers*

1. **Types.**—Boilers may be divided into three main types, viz. :—

Shell boilers.
Fire-tube boilers.
Water-tube boilers.

2. **Shell boilers** may be of vertical or horizontal type; the combustion chamber is usually circular and placed inside the shell. They are slow steaming and contain a large quantity of water. They may, therefore, be fired by less skilled attendants than the tubular types of boiler.

3. **Vertical boilers,** Pl. **96,** Fig. 1, are generally of small evaporating capacity, and are especially suitable for small isolated stations, where attendance is of low skill, because there is usually a fair depth of water above the crown plate when filled to working level. The flue which carries the products of combustion to the chimney is not in contact with water near the top, where the metal may be easily overheated. Therefore, these boilers should not be forced, and all combustion of gases should take place low in the combustion chamber, so that flames may not reach the unprotected portion of the flue.

4. **Horizontal boilers.**—These are commonly known as Cornish boilers, Pl. **96,** Fig. 2, when there is one flue, and Lancashire boilers, Pl. **96,** Fig. 3, when there are two flues.

The flues should be corrugated or strengthened by some means, such as Adamson rings, at frequent intervals; joints should be so designed that no rivet heads are exposed to the hot flue gases, which would burn them off very quickly.

On account of the large diameter of these boilers the bursting force on the plates is large. Therefore, such boilers are seldom worked at more than 200 lb. per square inch, and special attention must be paid to the prevention of corrosion in the plates, particularly where they are in contact with the brickwork setting. The large flat ends often found in such boilers are a source of weakness. They are usually strengthened by gusset stays and longitudinal stays, of which the inspection and proper maintenance is very important.

Dished ends should be specified when new boilers are installed. Stays are thereby rendered unnecessary, and expansion and contraction can take place freely.

5. **Brickwork settings.**—Horizontal boilers are usually set in brickwork, in which flues are provided; through these flues the hot gases are passed back along the sides and underneath, outside the shell, before they are released to the chimney. More heat is thereby extracted from the gases.

PLATE 96.

SHELL-TYPE BOILERS

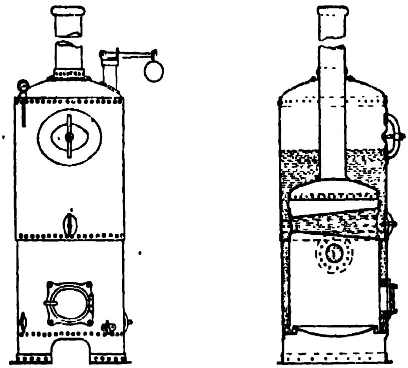


Fig. 1 VERTICAL BOILER

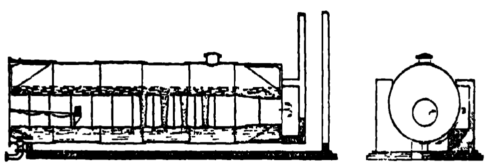


Fig. 2 CORNISH BOILER EARLY TYPE OF CONSTRUCTION

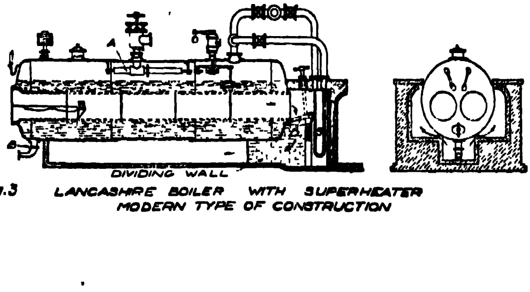


Fig. 3 LANCASHIRE BOILER WITH SUPERHEATER
MODERN TYPE OF CONSTRUCTION

In Cornish boilers the gases usually pass first along the sides and then beneath. Thus they are fairly cool when passing the bottom, in which sediment collects, and plates are less likely to be overheated.

In Lancashire boilers the gases usually pass first beneath the shell, where they heat the water considerably, thereby causing it to rise up between the internal flues, on the plates of which steam is principally evolved. Thus the circulation is improved. They return then along the sides, where, though already considerably cooled, they can still part with some heat to the descending water, of which the temperature has been reduced by the evolution of steam and by the addition of comparatively cool feed water. It is advisable to build a partition wall in the end chamber at the back of the boiler between the internal flue openings. A better and more regular draught is thus obtained.

The brick flues should be lined with firebricks. The brickwork should touch the shell as little as possible; the bricks in contact with riveted joints should be loose, so that they can be removed during inspection and the whole of the joint may be examined for signs of corrosion.

The outside surface of brickwork settings should be tarred, painted, or faced with glazed bricks or cement; otherwise air would be drawn in through the porous bricks, cooling the flue gases and spoiling the draught. The top of the shell should be tarred with Stockholm tar and covered with lagging, so arranged that it can easily be removed for inspection.

112. *Fire-tube boilers*

1. **Types.**—Fire-tube boilers comprise the locomotive type and also shell boilers, both of vertical and horizontal types, such as the marine boiler, of which the steam-raising capacity is increased by passing the hot gases through tubes surrounded by water after they have left the combustion chamber or internal fire flues. Occasionally, in horizontal fire-tube boilers, brick flues are provided in addition, as in the *economic* or *dry-back,* developed from the Lancashire boiler. Such boilers steam rapidly and contain less water than plain shells; therefore more care and skill is required on the part of the attendant, and the removal of scale is very much more difficult. Vertical fire-tubes are not very satisfactory when they project up into the steam space.

2. **Tubes.**—The tubes are small in diameter, and may, therefore, be of thin metal. This renders them efficient and unlikely to be burnt, provided they are well covered with water, and scale is not allowed to accumulate on them. The ends of fire-tubes are normally expanded into holes in flat

plates, often the end plates of the shell. These plates are much weakened by the holes, and when exposed to the full heat of the fire, as in the locomotive type, are very liable to be overheated, since the tubes impede the circulation of the water on the surface of the plate.

3. **Tube plates.**—The force used to expand the tubes, and the constant change of stress, due to their expansion and contraction, both circumferentially and longitudinally, tend to produce cracks between adjacent holes.

Sudden changes of temperature are, therefore, very injurious to these boilers. The tube plates must be examined frequently for such cracks ; they are difficult to repair, and if not attended to, the leakage from them causes rapid corrosion of the external surface. If several cracks occur, it is advisable to remove the whole plate and put in a new one.

If the plate is otherwise good, a tube-plate patch comprising all the tubes may be applied, the central portion of the old plate being cut away. This is a difficult operation, requiring very skilled work.

4. **Fireboxes.**—The firebox of a locomotive boiler, Pl. **97**, Fig. 2, and some others of the fire-tube type, is generally of rectangular form, and has flat sides which would collapse inwards if they were not held in place by a large number of stays, S, which connect them to the plates of the shell or outer casing.

The crown plate, C, being at a considerable distance from the top of the outer casing, is normally stayed by bolts, B, which sometimes are forged at the upper end to form forked links and bolted to angle-iron strips riveted to the outer boiler casing. Often bolts of ordinary shape pass through cast-steel girders which span the top of the firebox.

The side and end stays are threaded and screwed into both plates. The ends are left protruding about one diameter, and they are then riveted. Stays are normally of copper, but mild steel is used occasionally.

5. **Firebox stays** are very liable to corrosion, and often crack or break near the firebox plate. Broken stays may be detected by striking them lightly with a hammer ; the sound is dead and the hammer does not rebound.

A damaged stay must be drilled out and replaced.

The firebox is normally connected to the outer casing at the bottom by a solid base-ring of wrought iron. The rivets pass through both plates and the base-ring. Grooving of the plates is likely to occur along the edge of the ring.

6. **Locomotive boilers.**—The locomotive type boiler is specially designed to produce as large a quantity of steam as possible for its size and weight, Pl. **97**, Fig. 2. While very well

suited for this purpose, its construction is not conducive to longevity and freedom from breakdown.

The use of locomotive type boilers should be avoided in laying down stationary plant.

For temporary or semi-portable plant, such as a sawmill in the field, a portable boiler of the locomotive type has many advantages, and will be sufficiently reliable if used at a low pressure, such as 120 to 150 lbs. per square inch, and never forced.

113. *Water-tube boilers*

1. **Types.**—Water-tube boilers include many varieties of shell boiler whose steaming rate is improved by the provision of tubes containing water, around which the hot gases in the flues circulate.

Fire-engines and steam wagons are normally fitted with this type of boiler, of which the Merryweather, Pl. **97**, Fig. 1, and Sentinel, Pl. **97**, Fig. 3, are examples. Such boilers suffer in varying degrees from the same troubles as the locomotive types, chiefly due to the perforated tube-plates.

2. **True water-tube boilers** are those in which the main heating surface consists of tubes of comparatively small diameter which contain water. These tubes communicate with drums, whose purpose is to contain a quantity of water as a reserve store of heat and also to collect the steam which is produced in the tubes.

Good circulation is of paramount importance, as it is upon this that these boilers depend for safety and efficiency.

The drums are usually small in diameter, and well shielded from the hottest portions of the furnace gases. In consequence, high pressures can be used, and repairs to drums should not be necessary if they are well designed. The tubes are the only portions of the boiler which are exposed to the full heat of the furnace gases. They should be capable of being easily cleaned inside and outside, and if straight, have the advantage that they can be examined internally without being removed.

3. **The Babcock and Wilcox boiler,** illustrated on Pl. **98**, Fig. 1, has tubes expanded into headers, H, specially forged, so that any tube can be cleaned and examined with no more work than the removal of a small cover. Any tube can be changed without disturbing any others.

The drums are not weakened by any rows of holes, other than ordinary rivet holes. The headers, Pl. **98**, Fig. 2, consist of tubes of a special shape and are unlikely to suffer from cracks between tubes.

In case of damage, a new header tube can be fitted easily and at small cost. Sediment cannot collect in the tubes, but

PLATE 97.

SHELL-TYPE BOILERS ASSISTED BY WATER TUBES.

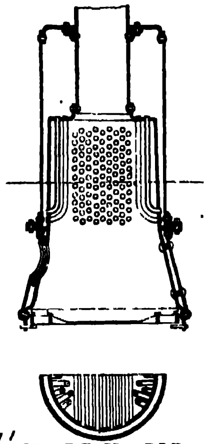


Fig 1 MERRYWEATHER FIRE-ENGINE BOILER QUICK STEAM RAISING

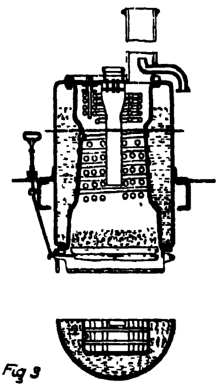


Fig 3 SENTINEL STEAM-WAGON BOILER. LARGER WATER SPACE.

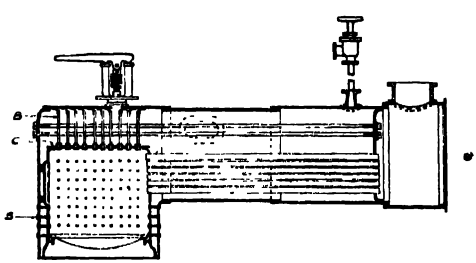
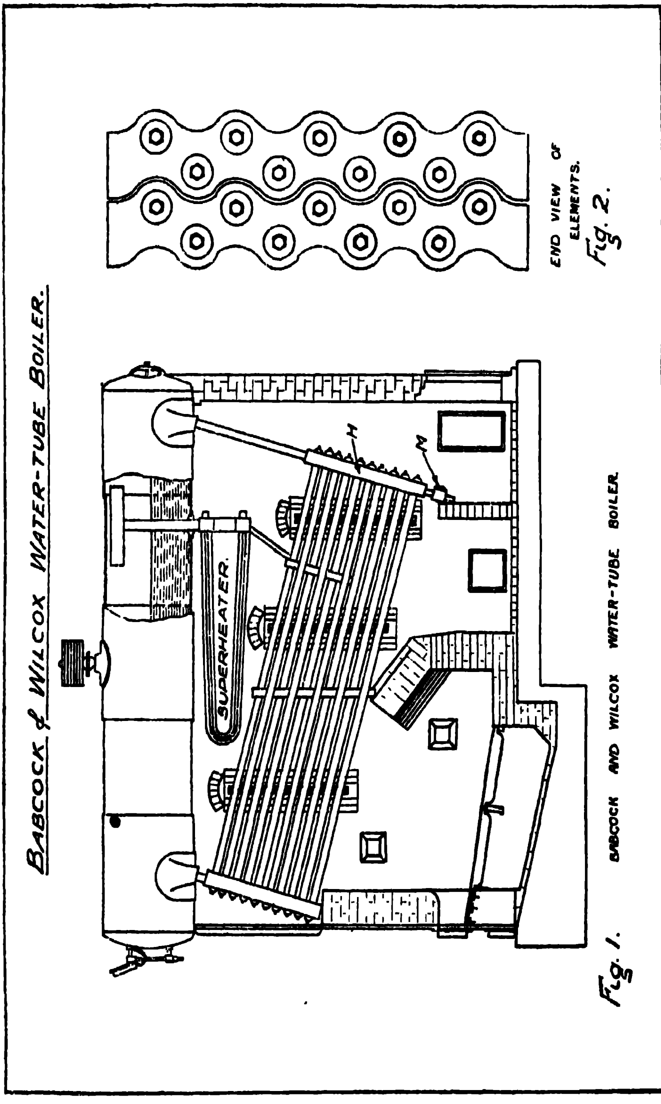


Fig 2. LOCOMOTIVE-TYPE SEMI-PORTABLE BOILER.

PLATE 98.


BABCOCK & WILCOX WATER-TUBE BOILER.
END VIEW OF ELEMENTS.
Fig. 2.
SUPERHEATER
H
M
BABCOCK AND WILCOX WATER-TUBE BOILER
Fig. 1.

falls to the mud drum, M. Steam is collected at the end of the steam drum farthest from the upward circulating headers, and is, therefore, obtained dry, with a minimum of priming.

4. The main points in favour of water-tube boilers are :—

i. That accidents are very rare, owing to the fact that only tubes of small diameter are exposed to severe heat.

ii. That a damaged tube can be quickly extracted and a new one fitted or its holes temporarily plugged.

iii. That they can be forced without strain.

There are in use a large number of water-tube boilers of other types. Many suffer from defects such as (*a*) excessive perforation of drum plates, when the tubes are expanded directly into the drums, and (*b*) curved tubes which are difficult to extract and impossible to examine internally.

Water-tube boilers are particularly suitable for superheating, since the superheater tubes can be situated between the boiler tubes or otherwise placed so that they are well heated without being burnt.

5. **Working of water-tube boilers.**—The comparatively small quantity of water held in reserve, and the complexity of the boiler, necessitate a high degree of skill on the part of the attendants. In large installations, where the necessary supervision can be provided, much economy and safety can be effected by the installation of water-tube boilers. They are not so suitable for small stations, where the boilers must normally be left to the care of inexperienced attendants.

The full efficiency of a water-tube boiler can never be obtained unless a large combustion chamber is provided, well lined with reverberatory walls of firebrick and, preferably, also provided with baffle walls, so that all the inflammable gases produced by the distillation of coal and also by the partial combustion of carbon may be completely burnt before the products come in contact with any of the metal of the boiler. Otherwise the flame is extinguished by contact with the relatively cool tubes, some gases remain unburnt, and tar and soot is deposited on the tubes. The Wood boiler, which transfers a high proportion of the furnace heat units by radiation on to the water-tubes, is an exception to this.

6. **Producer boilers.**—An interesting boiler arrangement is one in which the boiler has no firebars, but is heated by gas, which is generated in a producer below or beside it. The efficiency is high, as a very large percentage of CO_2 in the flue gas is easily maintained (18 per cent.). Extremely cheap fuel can be used in the producer—coke breeze or slack are quite suitable. A fan is essential.

For Bibliography, see page 689.

CHAPTER XXII

CARE, WORKING AND MANAGEMENT OF BOILERS

114. *General rules*

1. **Responsibility of the attendant.**—The engineer or boiler attendant is responsible for ensuring :—

That the following instructions and any others that may be posted up in the boiler-house are strictly carried out, subject to any special orders he may receive from his superior officer.

That the boiler and its mountings and all other machinery in his charge are kept clean and in proper condition.

That all injuries, defects and the necessity for repairs and painting are reported without delay.

That all pipes are in a safe condition for work.

2. **Economy.**—The attendant in charge of a boiler is responsible for its economical and efficient working. To ensure this he will periodically check the evaporation and fuel consumption. He will render monthly reports of fuel and engine time, in accordance with Regulations for Engineer Services, Peace, Part II.

The tubes of multi-tubular boilers will be swept out as often as required. Ashes must not be allowed to remain in the smoke box. Boiler flues will be swept out carefully and regularly. Brick flues will be swept at least every three months. Boiler settings and boiler mountings must be kept in good order, and leakages stopped without delay.

Priming may be due to dense water, insufficient steam space, and large fluctuations in steam pressure. The correct water level and steam pressure must be steadily maintained. Boilers should be fired often with small quantities of coal, and the furnace door not kept open longer than necessary. Smoke must be prevented by adjusting the air regulator and even by leaving the door open after firing sufficiently to provide enough air for complete combustion.

3. **The working pressure of the boiler must on no account be exceeded, and the safety valves must be set to blow at that pressure.** Safety valves must be so locked that they cannot be set to exceed the working pressure. They must be eased by hand periodically to make sure that they are working freely.

Care must be taken that the pipe connecting the gauge to the boiler is kept clear.

Pressure gauges must be compared with standard gauges at each half-yearly inspection. The working pressure should be indicated on the gauge by a red line. The working pressure will be stamped on the boiler front.

4. **The water level must be steadily maintained.**—Water gauges must be kept free and in good order. They must be tested frequently by blowing through. The passages connecting them to the boiler must be cleaned every time the boiler is cleaned out.

The feed pump and injectors must be in good order. The attendant must test them at short regular intervals.

At least two separate means should be provided for supplying feed water, and they should be used alternately to ensure that both are in working order.

Fusible plugs, Pl. **105,** Fig. 3, should be fitted to fire-tube boilers. They will be kept clean and free from scale. The cone will be removed every six months and replaced by a new one if necessary. The melting of a fusible plug is nearly always due to carelessness on the part of the attendant.

Large stationary boilers should be fitted with a high- and low-water alarm.

5. **External corrosion, Pl. 99, Fig. 1, will occur after a leakage at the boiler seams, manholes, plugs, pipe joints, or mountings, and any such leakage must, therefore, be stopped without delay.** Extensive leaks must be reported at once and be attended to by a skilled boilermaker.

When filling the boiler, particular care should be taken not to allow the water to overflow or upset where it can lodge between the boiler plates and the lagging or brick setting. The front of the boiler below the furnace must be frequently scraped and painted.

Ashes must not be allowed to lie against the boiler front, and they must be drawn well away from the boiler before water is thrown on them.

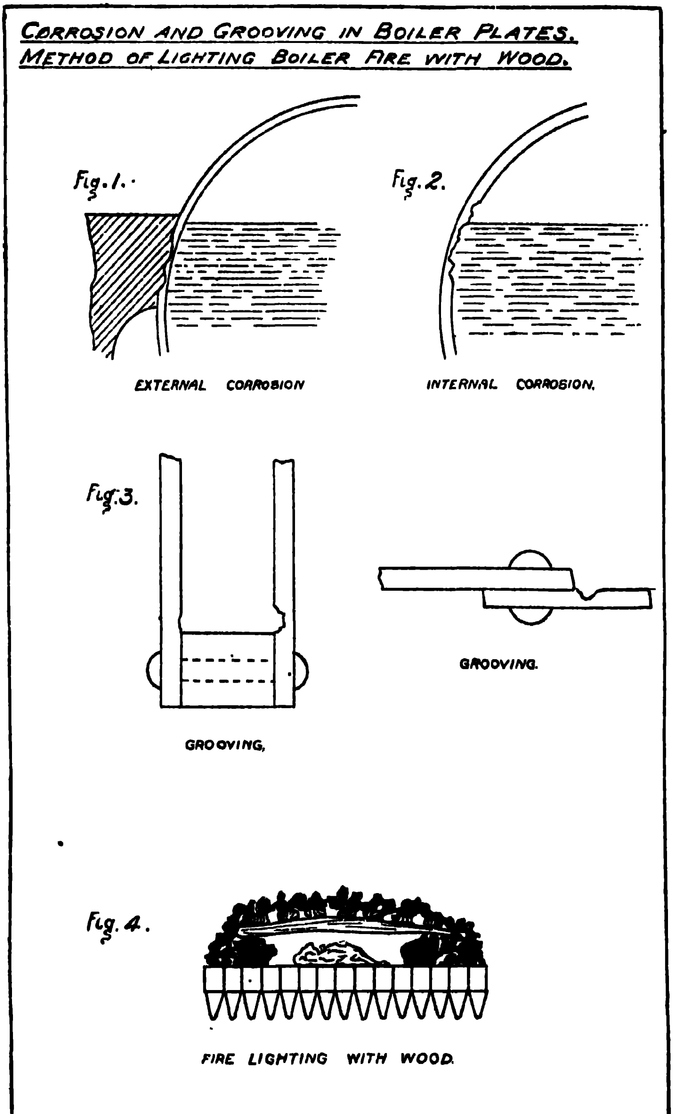
External corrosion, when discovered in the incipient stage, must be stopped by careful scraping and painting.

6. **Internal corrosion** is due to the action of acids in the water upon the metal of the plates, Pl. **99,** Fig. 2.

Tallow or oil must not be allowed to enter the boiler on any account. Tallow and many oils decompose at high temperatures into acids.

Zinc plates must be installed in every boiler so attacked, and renewed as they become eaten away. They must hang below the water level, but must be in good metallic connection with

PLATE 99.


CORROSION AND GROOVING IN BOILER PLATES.
METHOD OF LIGHTING BOILER FIRE WITH WOOD.
Fig. 1.
EXTERNAL CORROSION
Fig. 2.
INTERNAL CORROSION.
Fig. 3.
GROOVING.
GROOVING.
Fig. 4.
FIRE LIGHTING WITH WOOD.

the boiler above the water level. If corrosion takes place, they should be hung near the place where it is most active. The effect of the zinc is to neutralize the effect of acids in the water. Compositions for prevention of boiler corrosion are not to be used without War Office authority. [*See* R.E.S., Part II.]

Corrosion may be checked by scraping clean and treating with cement wash.

Corrosion is generally found at the working water level, but may also occur in irregular pittings all over the wetted surface.

Grooving, Pl. **99**, Fig. 3, is corrosion due to the opening of the grain of a plate at the junction of a stiff portion and weaker portions of a boiler shell. The large flexure which occurs at such points with every change of temperature opens the grain of the metal, and so allows acids to attack it more readily.

7. **Boilers laid off.**—When a boiler is laid off for a short period, it should be completely filled with clean fresh water to which caustic soda has been added, either in the proportion of 1 lb. of caustic soda to 1 ton of water, or in such quantity as may be necessary to render the water slightly alkaline. If caustic soda is not obtainable, washing soda crystals may be used, but the proportion in this case is to be 1 lb. of soda to 1 cwt. of water.

The boiler should be thoroughly examined externally to ascertain if any leaks exist, and it should be kept full of water till again required for use. When it is found difficult to keep the boiler completely filled, or when it is exposed to frost or laid off for a long period, it should be emptied, carefully dried, and closed up airtight after inserting quicklime in a sheet-iron tray. A board bearing the word *empty* must then be hung on the front of the boiler. Water must not be left in a boiler at the normal working level.

Boilers laid up in store for any length of time should be painted externally with oxide of iron paint, and their fittings removed and wooden blank flanges fixed in their place.

8. **Blowing down.**—A boiler should be blown down as often as required, to remove as much as possible of the sludge which collects in the bottom. This is particularly important in types such as the locomotive boiler, where the water space round the firebox is small.

Before drawing the fire, or before the pressure has dropped too much, the boiler should be filled up above the gauge glass and left for the dirt to settle down until there is little or no pressure.

When pressure has dropped sufficiently, the blow-down

cock, B, on Pl. **96**, Fig. 3, may be opened, and the sludge allowed to run out till the water is at working level if the boiler is to be used next day.

9. **Washing out.**—Boilers in daily use should be washed out frequently, the intervals depending upon the nature of the feed water, *see* R.E.S., Part II. Boilers using crude or untreated water should be washed out at least once a fortnight. Manholes and mudholes should be opened and a stream of water from a nozzle on a fire hose directed into them until clear water flows out from the lower mudholes.

The scale that adheres to the firebox top and in the water space must then be dislodged with a suitable scraper, which can be made by flattening the ends of a ¾-inch steel bar, and bending one end to form a hoe, leaving the other straight with a chisel point. This loosened scale must now be washed out, and the scaling operation repeated if necessary until no more can be found. Particular attention should be given to the space just above the base-ring and to the spaces between the girders on the firebox top.

115. *Inspection and insurance*

1. **Preparation.**—The inspection and insurance of all steam boilers at work in Great Britain are secured by means of running contracts with certain companies and associations.

The boilers are inspected by the contractors twice a year. Instructions for these tests are contained in Regulations for Engineer Services, Peace, Part II.

It is important that boilers should be properly opened up and cleaned for entire inspection. Every portion of the internal and external surfaces must be, as far as possible, clearly visible and absolutely free from scale, sediment, soot and rust.

2. **To test a boiler hydraulically,** fill it quite full of water and then apply pressure gradually by means of a hand pump. After ascertaining that the safety valves lift at the right pressure fasten them down and gradually increase the pressure to the prearranged amount. While the pressure is being raised, care will be taken to note whether the pressure registered on the gauges on the boiler corresponds with that on the standard gauge.

The hydraulic-test pressure will only be maintained long enough to enable a thorough inspection of the boiler to be carried out to determine whether it is tight under pressure, and whether bulging, showing some weakness, is occurring.

Special attention should be paid to the tube-plate and firebox.

3. **The steam test** comprises a careful examination of the boiler to see whether all joints, stays, &c., are steam tight, and is carried out under normal working conditions. The safety valves should lift at the proper pressure, as indicated by the gauge, or should be set to do so.

116. *Coal-fired boilers*

1. **Laying the fire.**—The fire in a boiler furnace should be started with a small quantity of wood shavings and kindling wood, *not with oil.* To ensure that the fire lights quickly and spreads rapidly over the grate, it is necessary to prevent air passing up through any portion of the grate where the fire is not burning. This can be done by spreading coal or paper over the bars when laying the fire, if no other means is provided.

The procedure is as follows :—

Clean the bars thoroughly of all ashes, clinker and cinders. Spread clean coal, without dust or slack, over the whole grate to a depth of about 3 inches, except for about a square foot where the fire is to be lighted. Here place two handfuls of dry wood shavings. In this space place the kindling wood. This should be laid in two or more layers, the sticks being laid with about one-inch gaps and the second layer crossing the first at right angles, Pl. 99, Fig. 4. The wood should rest on coal at its ends, not on shavings. Spread small pieces of coal over the sticks.

2. **Lighting.**—See that the water level is correct. Light the shavings and, when well alight, close the door and wait for the wood to light. A fire so lighted will burn brightly from the start and will spread rapidly.

At intervals of about one minute a small shovelful of selected small coal, free from dust, should be sprinkled over the hottest portion of the fire. Paraffin or other oil must on no account be used in lighting or drawing up a fire.

3. **Coal.**—Ordinary steam coal contains a large proportion of carbon and also large amounts of gases, oils and tar, nearly all of which can be burnt. When coal is heated without actually burning, these volatile portions are driven out as coal gas. There is also a small amount of earthy matter which cannot be burnt and will remain as ash.

4. **Air** is chiefly a mixture of nearly one part of oxygen and 3 parts of nitrogen by weight, or, more accurately, 23 per cent. oxygen and 77 per cent. nitrogen.

Combustion is really a rapid combining of the oxygen in the air with the carbon and other combustible portions of the

coal, and forms other compound gases. Nitrogen is quite useless for combustion.

5. **Combustion** cannot be complete unless enough oxygen is present to combine completely with all the fuel. If there is not enough air present, there will not be enough oxygen; instead of producing fully burnt gases only, there will be also a portion of carbon monoxide, a very poisonous and inflammable gas formed by the combination of carbon with half the correct amount of oxygen.

When carbon burns to form carbon monoxide, it only produces 4,400 B.Th.U. per lb., whereas 14,500 are produced when it is fully burnt to form carbon dioxide. If the monoxide is mixed with more air and burnt, the lost 10,100 B.Th.U. are recovered.

6. **Coal distillation.**—When coal is put on to a fire, the first thing that happens is that the gases and then the oil and tar are driven out of it in heavy greenish smoke. These can only be burnt when mixed with air, and unless they are burnt at once, they go up the chimney and are lost. As the coal gets hotter, the carbon begins to burn, but the air which comes up through the fire does not contain enough oxygen to burn it completely, and much carbon monoxide is formed. Unless this carbon monoxide is mixed with more air and burnt at once, it also goes up the chimney and is lost.

7. **Air regulation.**—1 lb. of coal can be burnt with $11\frac{1}{2}$ lb. of air, but, with stoker boilers, it is found in practice that from 17 to 20 lb. of air are necessary to burn 1 lb. of coal completely. This is a very large amount of air, and it frequently happens that enough cannot get through the firebars, especially immediately after firing, when large quantities of combustible vapours are pouring off from the fresh coal.

More air should be supplied just after firing, reducing the amount slowly as the fire clears.

A deep humming or buzzing noise, known as down-draught, means that the draught is irregular or alternating, and indicates either a hole in the fire or insufficient air, generally the latter. The vibration is harmful to the boiler and should be stopped at once.

8. **The rules of firing are, therefore :—**

i. *Fire little at a time and often.*—The fire then keeps fairly thin, air can get up through it easily to burn the carbon, and only a small amount of green smoke gas is given off at a time. The fire also keeps hot, whereas, if much coal is put on at one time, it cools down and the boiler pressure falls, Pl. **100**, Fig. 1.

ii. *Fire evenly* all over the grate, Pl. **100**, Figs. 2 and 3. Thin patches quickly burn away to *holes*, which allow air to be drawn through without burning any coal. The air chooses the easiest path and goes up through the holes instead of through the thicker parts of the fire where it is needed, so that coal tends to burn around the holes only and to make them larger.

iii. *Regulate the air.*—Open the main damper enough to keep the pressure up, but not enough to blow off. Keep the fire door open enough to burn all the gases and stop all smoke when a new charge is put on. Then shut it gradually and keep it shut until more coal is required.

Pl. **100**, Fig. 4, shows the correct method of firing.

9. **The ideal of firing** is to burn completely every atom of the fuel fired on, or immediately above, the grate, using only enough air to effect this combustion thoroughly; thus all the available heat from the fuel is carried by the hot air and gases to the boiler at the highest possible temperature. It is, however, far better to use too much air than too little. CO and CO_2 indicators are of great use in this connection.

For the best results the CO_2 percentage should be as high as possible and the CO negligible. It will be clear from Pl. **99A**, that CO_2 readings between 6 per cent. and 13 per cent. give no clue as to whether there is too much or too little air. To decide this, the CO content must be known as well.

10. **The deflector** used in many fire doors, Pl. **101**, Fig. 1, especially of locomotive type boilers, guides the air coming in through the door down on to the top of the fire where it is required, and where there is a high enough temperature to make sure that the gases burn completely.

11. **The brick arch** in a locomotive boiler, Pl. **101**, Fig. 1, and the brick bridge in a Lancashire boiler, Pl. **101**, Fig. 2, are placed there chiefly to keep the air and gases a little longer in the hot firebox, and so give them a better chance of burning completely before they pass into the cooler flues. There the flame would be quenched at once, and smoke and soot would be formed. When once the gases are properly burnt no smoke or soot can be formed. The bricks get red hot and so help the combustion.

12. **Rate of combustion.**—The rate at which coal is burnt should be controlled entirely by opening or closing the main damper. If an ashpit door is fitted under the brick bridge, it should never be open while the boiler is working.

PLATE 99A.

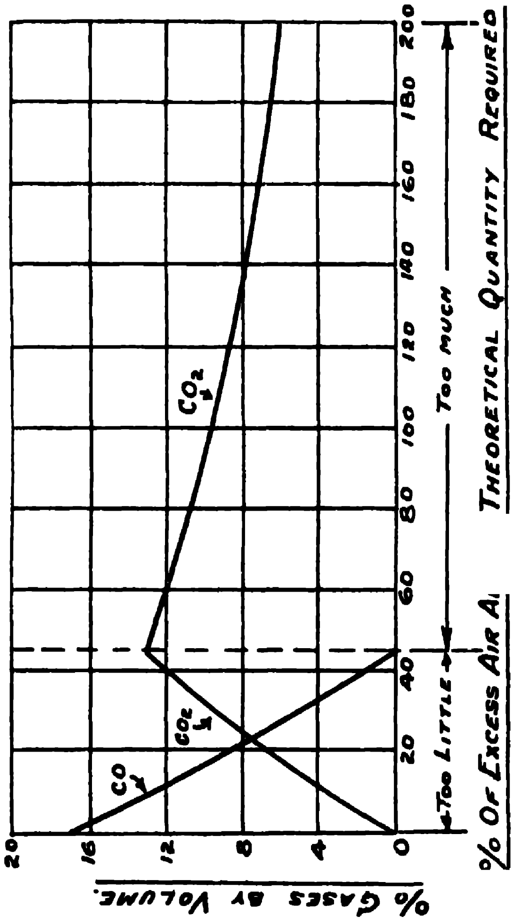

CO₂
CO
0
4
8
12
16
20
0
20
40
60
80
100
120
140
160
180
200
Too Little
Too Much
% Of Excess Air A
Theoretical Quantity Required
% Gases by Volume.

PLATE 100.

FIRING BOILERS - FAULTY AND CORRECT FIRES.

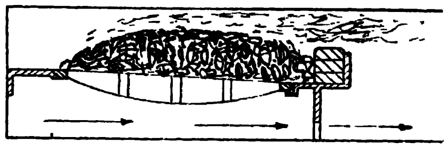


Fig 1. FIRE TOO THICK

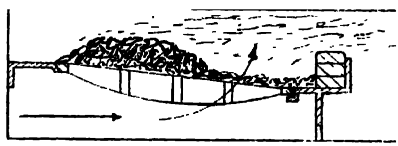


Fig 2. FIRE THICK AT ONE END

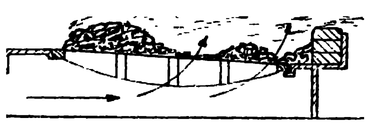


Fig. 3. FIRE UNEVEN

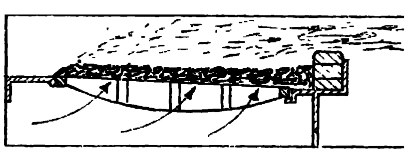
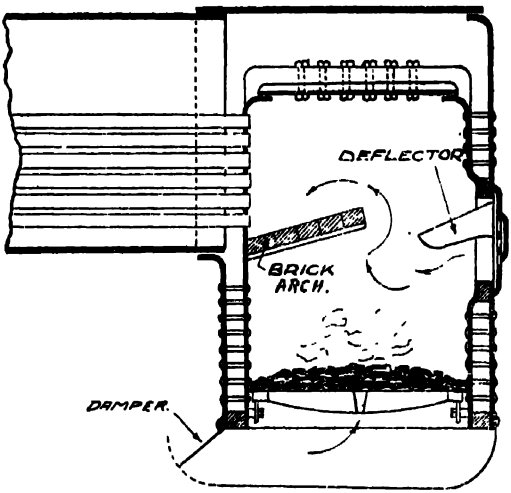


Fig. 4. GOOD EVEN FIRE

Plate 101.

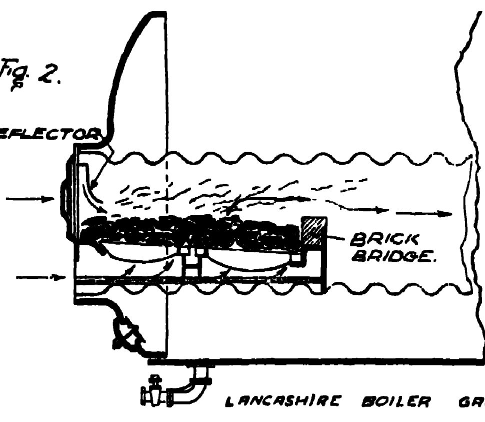
FIRING BOILERS – LOCOMOTIVE & LANCASHIRE TYPES.

Fig. 1



LOCOMOTIVE – TYPE FIREBOX.

Fig. 2.



LANCASHIRE BOILER GRATE.

If it were open, cold air would be going into the flues without passing over or through the fire. It could not help at all in finishing combustion, and would merely cool the flues without serving any useful purpose.

117. *Oil fuel*

1. **Reasons for use.**—Oil as a fuel for steam boilers is very suitable for service purposes for the following reasons :—

- i. Its calorific value is high, thus reducing the weight of fuel required.
- ii. Its efficiency is very high if it is burnt under correct conditions.
- iii. It gives nearly a smokeless fire at all times if properly burnt.
- iv. Its cost in many countries in which British troops are liable to operate is no higher than that of coal.
- v. Oil must be provided in large quantities at oversea bases for supplying covering warships with fuel, and should, therefore, be easily obtainable from naval supply vessels.
- vi. It is easily handled at ports at which no facilities exist for handling coal, since its unloading or transhipment necessitates only a pump and suitable piping, provided the temperature is high enough to ensure that the oil is liquid.

2. **Fuel oils available.**—The oils mostly used for burning under boilers are :—

- i. Residual oils, resulting from the distillation of petrol spirit and the lighter burning oils from the crude product.
- ii. Tar oils, the by-products of fractional distillation of coal and oils; in the production of gas, benzole, coke, &c.
- iii. Shale oils, obtained by the destructive distillation of the mineral shale.

3. **Oil combustion.**—All these fuel oils have a calorific value exceeding that of coal, varying from 16,000 to 20,000 B.Th.U. per lb.

Oil, suitably atomized or vaporized, can be burnt completely without smoke or waste when mixed with only so much air as is necessary to supply sufficient oxygen to combine chemically with the hydrogen and carbon present. The flame is much hotter than can be obtained by the use of coal upon a grate, due to :—

- i. The smaller amount of air to be heated in the flame.
- ii. The higher calorific value of a given weight of fuel.

In practice it is necessary to admit from 10 per cent. to 30 per cent. excess air to give complete combustion without smoke. Combustion efficiency is increased by :—

i. Complete atomization of the oil.
ii. Thorough mixing of fuel and air.
iii. Preheating the air.

4. **Oil-burning systems.**—There are three main systems of atomizing the oil and burning it :—

i. Steam injection.
ii. Air atomization—
 (*a*) Low pressure air from a fan at from 9 to 15 inches water gauge.
 (*b*) Medium pressure air from a rotary compressor, 1·5 to 5 lbs. per square inch.
iii. Pressure-oil system.

Of these, the steam injection system is much the simplest if steam is available, but some complication is caused by the fact that until steam is obtained at sufficient pressure to operate the nozzles some other method of firing must be applied.

The compressed-air system necessitates the addition of a fan or compressor, which, moreover, is possibly driven by steam, and cannot be used until steam has been raised by some other method of firing.

The pressure-oil system is complicated by the necessity for a pump to force the oil out of spraying nozzles at sufficient pressure to ensure perfect atomization, and, in cold climates, for some system of heating the oil to render it sufficiently liquid to be readily pumped and atomized. It has, however, the compensating advantage that the amount of power required to drive the oil-pump is small, and, therefore, that the oil atomizers can be used from the start by the use of a hand pump and separate heating lamp.

5. **The relative efficiencies** of the three systems are in the order: pressure, air, and steam. The differences are not very wide, being about 5 per cent. between each; but varying with the nature and size of the plant.

The lower efficiency of the compressed-air system is due to the low temperature at which compressed air emerges from a nozzle.

The still lower efficiency of the steam system is due to the use of a large amount of steam, which is not only wasted, but by its presence lowers the flame temperature.

6. **The steam system.**—There are several varieties of nozzle which give satisfactory results. All work to some extent on the principle of the ordinary boiler injector.

Pl. **102**, Fig. 1, illustrates a Babcock and Wilcox burner, and Pl. **102**, Fig. 4, a Wallsend-Howden burner. Steam is admitted into the expanding nozzle, S. Oil is fed by gravity into the pipe, O, and entrained in an atomized state with the steam jet. The tanks should, therefore, be 10 to 12 feet above the burners to ensure a free flow. The burner is normally fitted centrally in the fire door and throws its flame horizontally, or slightly downwards, into a large firebrick-lined combustion chamber.

The flame is about 6 feet long, and should be given ample distance in which to complete its combustion before touching any tubes or plates.

In locomotive type boilers the flame must be well baffled by at least a large brick arch, so that it cannot play upon the tube or firebox plate.

Pl. **102**, Fig. 2, illustrates the Scarab type of burner, which is specially suitable for very crude oils containing quantities of foreign matter which might clog a nozzle. The oil is merely allowed to pour through the open pipe, O, on to a heating plate, P, under which the steam passes. The oil then flows over the serrated edge, E, in a flat band, and is carried forward upon the steam jet, S, in a fairly well atomized condition.

7. **The compressed-air system** has little to recommend it from the service point of view. Where another source of power is available to drive a compressor, any nozzle type of burner may be used with compressed air instead of steam, thus facilitating the starting-up by providing a flame before steam has been raised.

8. **The pressure-oil system.**—In this system, the oil is first slightly warmed by steam pipes in the service tanks to render it fairly liquid. It is then pumped into a vessel containing a quantity of imprisoned air, which ensures a continuous and almost constant pressure of about 40 lbs. per square inch or less according to the viscosity of the oil.

From this pressure-vessel it travels through a filter and through pipes either steam heated or placed in the brickwork setting of the boiler, in which it is heated to a temperature of 150° to 240° F., depending upon the viscosity of the oil. At starting, a separate oil-heating stove is used. An electrical immersion heater, often thermostatically controlled, is frequently used for oil heating nowadays, as it gives excellent oil temperature regulation. Heating above the flash point must of course be carried out under pressure.

Finally the fuel is sprayed into the firebox or combustion chamber through a fine nozzle, which ensures thorough atomization.

Pl. **103** and Pl. **102**, Fig. 3, show a section through the nozzle-plate type of pressure-oil burner. The air, entering

Plate 102.

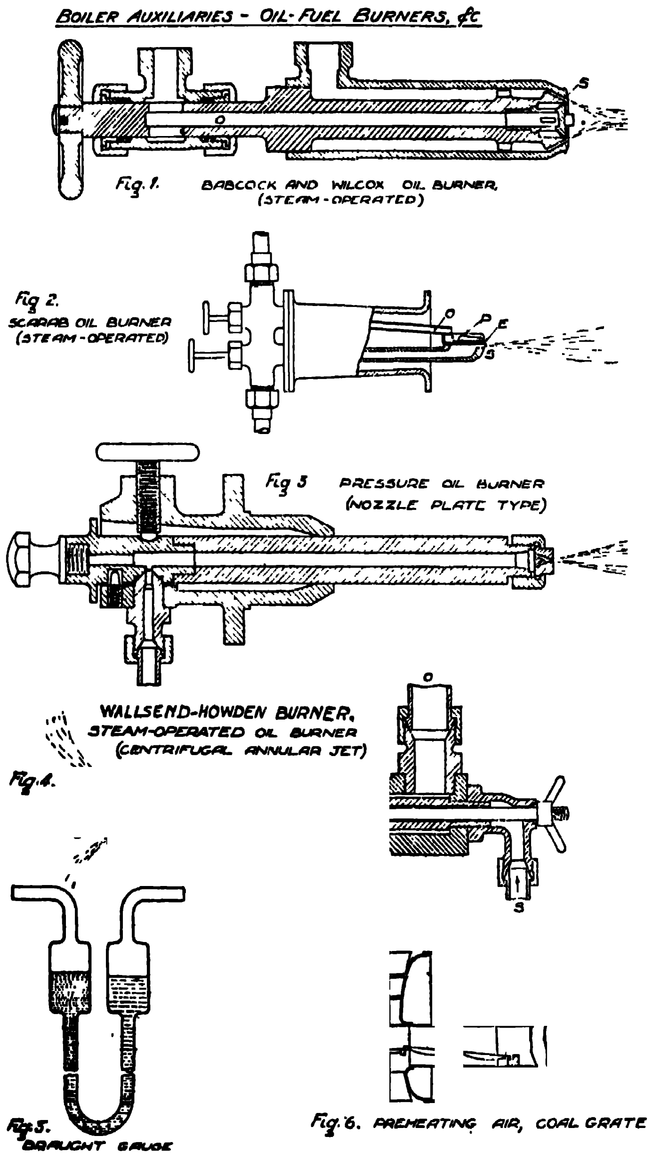
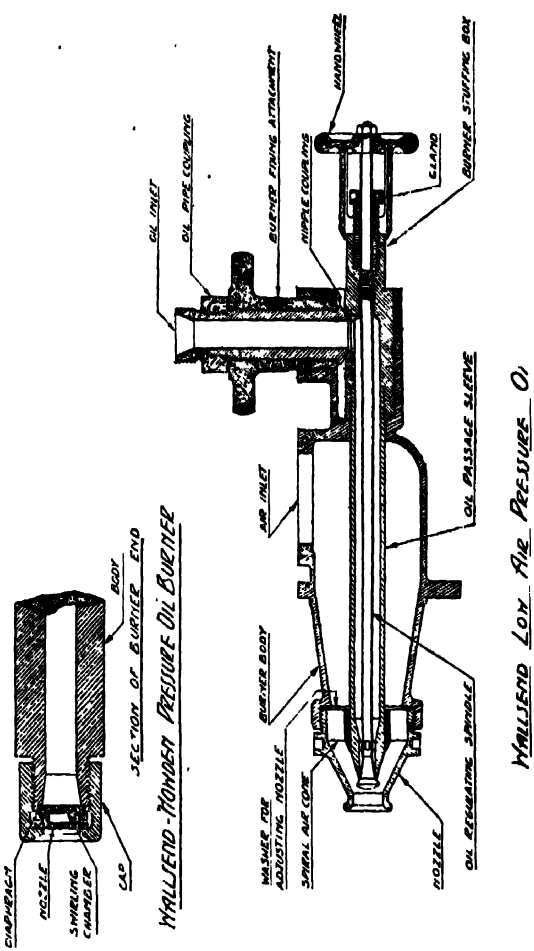

BOILER AUXILIARIES - OIL-FUEL BURNERS, &c
S
O
Fig. 1. BABCOCK AND WILCOX OIL BURNER. (STEAM-OPERATED)
Fig 2. SCARAB OIL BURNER (STEAM-OPERATED)
O
P
E
S
Fig 3 PRESSURE OIL BURNER (NOZZLE PLATE TYPE)
WALLSEND-HOWDEN BURNER. STEAM-OPERATED OIL BURNER (CENTRIFUGAL ANNULAR JET)
Fig. 4.
O
S
Fig. 5. DRAUGHT GAUGE
Fig. 6. PREHEATING AIR, COAL GRATE

PLATE 103.


BODY
DIAPHRAGM
NOZZLE
SWIRLING CHAMBER
CAP
SECTION OF BURNER END
WALLSEND-HOWDEN PRESSURE OIL BURNER
OIL INLET
OIL PIPE COUPLING
BURNER FIXING ATTACHMENT
NIPPLE COUPLING
HANDWHEEL
GLAND
BURNER STUFFING BOX
AIR INLET
OIL PASSAGE SLEEVE
BURNER BODY
WASHER FOR ADJUSTING NOZZLE
SPIRAL AIR CONE
NOZZLE
OIL REGULATING SPINDLE
WALLSEND LOW AIR PRESSURE OI

through the fire door round the nozzle, should be preheated and in a state of powerful rotary turbulence to ensure thorough mixing and combustion.

This may be accomplished by drawing in all air between the boiler face and a plate fixed a few inches from it, the intervening space being occupied by a number of guide vanes to impart the necessary rotary motion to the draught.

Artificial draught is not essential, but it is advisable when a good chimney is not available.

9. **Simultaneous coal and oil firing.**—An oil burner of any type may be used simultaneously with a coal fire to take an overload or to render possible the burning of poor grades of coal. The ordinary firebars should be in place, and the burner may be fitted to the door with hinged piping or flexible hose. It may alternatively be fitted anywhere else, *e.g.* in the side walls of a water-tube boiler inclined downwards to play on to the coal fire. In the latter case, if the oil alone should be used, the firebars should be covered with loose bricks to protect them, and also to limit the supply of air other than that entering alongside the jet.

10. **Instructions for starting and working.**—

i. Oil burners are lighted by means of a torch made by twisting a handful of cotton waste into the bend or bight of a doubled piece of stout wire.

The torch should be dipped into oil, lighted, and held in front of, but below, the burner. The oil may then be turned on gradually, after first turning on steam or compressed air, if used. The flame should then be adjusted by altering the relative quantities of fuel and air entering, till there is only a little light brown smoke, but only enough air should be admitted to ensure this. Any excess of air militates somewhat against efficiency, while shortage of air will cause heavy black smoke. The torch should be kept handy for relighting, in case the flame should go out, until the bricks are thoroughly hot.

ii. The size of flame may be reduced at will by partly closing the oil-valve, and making a corresponding decrease in the amount of air. Partly closing off the steam, if used, will also reduce the amount of induced air.

In the oil-pressure system, the air inlet should be closed gradually until black smoke is produced, and subsequently reopened until a slight haze is visible. A CO_2 content of about 12 per cent. may then be expected.

iii. The flame may be extinguished at once by closing the oil-valve. In turning off any burner, it is important to turn off the oil first. When turning on a burner, it is most important to *turn on the oil after the steam or compressed-air valves have been opened.*

iv. If the flame should be extinguished accidentally, it will probably be caused by dirt accumulation in the oil nozzle. The burner should be turned off at once, withdrawn and cleaned and subsequently relighted as in (i). Any grit or other dirt in the oil or steam pipes will be drawn eventually into the jet, causing bad burning and perhaps extinction of the flame, besides making the lighting-up difficult or impossible. Therefore, provision must be made for cleaning the nozzles.

v. No cotton waste should be used in cleaning, since it eventually gets into the jets and clogs them.

vi. Care must be exercised that no unburnt oil is allowed to accumulate in the furnace or flues, owing to valves leaking, failure to observe the extinction of a flame, or an unsuccessful attempt to light a burner. Such oil may produce an explosive mixture in the flues and cause a disastrous explosion. Air or steam valves should be left open for a few minutes between each attempt to relight a burner to blow away all fumes of unburnt oil.

vii. An ample supply of sand should be kept in the boiler-house for dealing with any outbreak of fire. Water is useless for extinguishing burning oil.

viii. Any leaks in tanks or pipes must be stopped at once, since oil vapour is inflammable. On no account must a naked light be taken into or near an open tank, even if empty, nor near any pools of escaped oil. Such pools should be absorbed in sand, and the sand taken outside into the open air.

ix. All pipe joints should usually be metal to metal. No packing or jointing of the normal steam practice type should be used in the oil pipes. Any attempt to use it would lead to stoppage of the nozzles, owing to particles travelling along with the oil. Certain oil-resisting compounds can, however, be employed with success on joints.

CHAPTER XXIII

BOILER FITTINGS

118. *Fittings on the boiler*

1. List of fittings.—Every boiler should be provided with the following fittings :—

i. Safety valve.
ii. Pressure gauge.
iii. Anti-priming pipe or steam dome.
iv. Water gauges.
v. Fusible plug (on fire-tube boilers).
vi. Internal feed pipe.
vii. Feed check valves (*two*) with stop cocks.
viii. Blow-down cock.
ix. Injectors or feed pumps.
x. Main stop valve.

A large boiler may also be fitted with :—

xi. High- and low-water alarm.
xii. Feed water regulator.

2. **Safety valves** are of several types. All consist essentially of a metal valve which is normally kept closed by either a weight or a spring, either directly or by means of a lever.

Deadweight valves, Pl. **104,** Fig. 1, are simple and effective on stationary boilers. They cannot easily be tampered with, but are difficult to ease by hand on account of their great weight.

Lever valves, Pl. **104,** Fig. 3, are more convenient for easing by hand, but are open to the objection that the position of the weight upon the lever is easily altered, and a small alteration is not very noticeable.

Spring-loaded valves, Ramsbottom type, Pl. **104,** Fig. 2, are essential for portable boilers, locomotives, and ships' boilers, which are subject to jarring and tilting.

Safety valves must be large enough to allow the full amount of steam produced by the boiler to escape, should the engine be suddenly shut down. The valve, V, on Pl. **104,** Fig. 3, should be capable of being turned on its seating, S, for grinding in.

3. **Pressure gauges** are normally of the Bourdon type, Pl. **105,** Fig. 1, in which a curved tube, T, of oval section is in communication with the boiler. The effect of the steam pressure inside the tube is to make it less oval. In consequence the curvature of the tube is decreased. The tube is fixed at

PLATE 104.

BOILER FITTINGS - SAFETY VALVES.

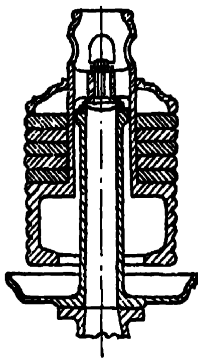


FIG. 1.
DEADWEIGHT
SAFETY VALVE

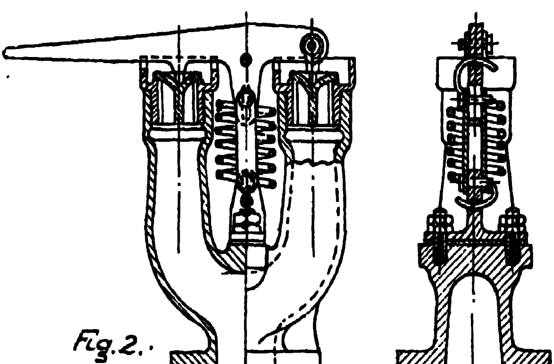


FIG. 2.
SPRING-LOADED SAFETY VALVE.

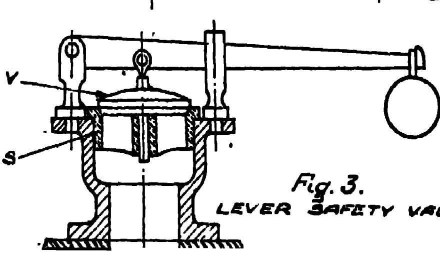
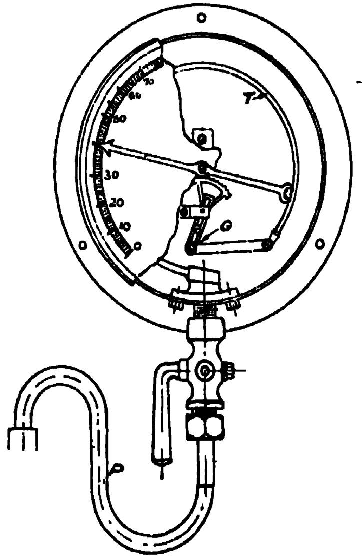


FIG. 3.
LEVER SAFETY VALVE.

PLATE 105.

BOILER FITTINGS - GAUGES & FUSIBLE PLUG.

Fig 1. STEAM PRESSURE GAUGE



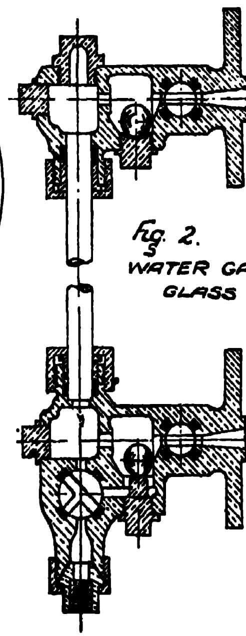


Fig. 2. WATER GAUGE GLASS

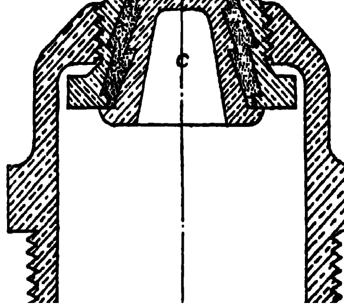


Fig. 3. FUSIBLE PLUG

one end, and the other end is free to move. Its movements are magnified by a suitable multiplying gear, G, and indicated by a pointer.

Such gauges require periodical testing, since the tube is liable to take a small permanent set.

Normally, gauges are graduated to show pressure above that of the atmosphere, so that a figure corresponding to the barometric pressure must be added if the absolute pressure is required. Pressure gauges are fixed by a curved pipe, P, so that condensed and not live steam is acting on the flexible tube. The working pressure should be marked by a red line.

Vacuum gauges are of similar construction, except that their movement is more highly multiplied and the dial is graduated backwards, showing atmospheric pressure as zero.

4. **The anti-priming pipe,** A on Pl. **96,** Fig. **3,** is a device for separating the water spray, which is always present in the steam, in the steam space of a boiler. It usually consists of a horizontal pipe of large bore, in the top of which are large slots through which the mixture of steam and spray can enter easily. The steam then turns abruptly along the pipe towards the open stop-valve, while the water, being heavier, settles at the bottom of the pipe and then runs out again through holes provided for the purpose.

5. **Water gauges** are provided to indicate the level of the water in the boiler. The glasses are normally held in rubber joints carried by two brass fittings, one well above the working water level and the other below it, Pl. **105,** Fig. **2.** Both fittings are sometimes provided with cocks and with ball valves, arranged to close if the tube should burst. The lower fitting must be provided with a blow-down cock also, so that the glass can be blown through to clean it and the passages between it and the boiler.

Two gauge glasses must always be supplied as tubes are liable to burst at any time.

Glass shields (not shown in Pl. **105,** Fig. 2) must be fitted to stop the fragments when a gauge tube bursts ; otherwise the attendants might be seriously injured.

6. **Fusible plugs** are devices for preventing serious explosions due to a low water level and have usually a bronze body, Pl. **105,** Fig. **3,** in which a central bronze cone, C, is retained by a lining of fusible metal, M, generally lead, or a lead and tin alloy, melting at 400° to 500° F., according to the working pressure. If the water falls below the level of the crown plate, the latter will rise in temperature. A fusible plug screwed into it will then melt out and the cone will blow out bodily, leaving a large passage through which enough wet steam can escape to quench the fire.

Spare plugs should be kept and should be used to replace the existing one at least once a year, as the properties of the fusible metal change on prolonged heating. Fusible plugs must be kept quite clean on both fire and water sides or they are useless.

Fusible plugs are usually placed directly over the fire.

119. *Injectors and feed pumps*

1. **Injectors** for feeding water into boilers are of non-lifting or lifting types, according to their capacity for raising water into themselves from a lower level. Exhaust injectors are designed for the utilization of steam at approximately atmospheric pressure : they are non-lifting.

The principle upon which all injectors work is that steam is allowed to escape to atmosphere through a jet, J, on Pl. **106,** Fig. 1, from which it issues with great velocity, having expanded in the jet so that its pressure is reduced. Sufficient cold water is then allowed to enter through W and mix with the steam to absorb all its latent heat, whereby all the steam is condensed, while the water is considerably heated. The mixture of steam and water resulting from the condensation, and the now warmed feed water, continues with reduced velocity through the mixing tube, M, the condensed steam being finally represented by a fine thread of water, entraining or dragging along with it the added feed water.

The mixture now passes along a delivery tube, or infuser, I, which is gradually enlarged. Since the quantity of water flowing through this tube per second must be the same at all points along it, the velocity falls as the area increases, and the energy, which was present as velocity only, becomes partly turned into pressure. This delivery tube is, therefore, enlarged sufficiently to ensure that the pressure rises above boiler pressure.

From the above description it will be seen that the feed-water should be cold, and that the amount allowed to flow into the mixing tube must be capable of being controlled, so that there is enough to condense the steam entirely but not enough to slow down the mixture too much.

In practical injectors, an overflow, O, is provided between the mixing tube and the delivery tube, so that any excess of steam or water can escape. A non-return valve is provided in the delivery tube so that water cannot be blown back from the boiler into the injector when the latter is not working.

In the non-lifting type of injector the feed water must be fed into it by gravity.

Exhaust-steam injectors require a very large steam jet, on account of the large bulk of steam. Since all the heat

in the steam used passes back into the boiler, injectors are economical.

2. **Lifting injectors.**—When high-pressure steam is used, an injector may be made to lift water into itself from a tank placed slightly below it. The steam jet, when first turned on, reduces the pressure in the mixing tube to a little below atmospheric pressure, provided there is a free exit for the steam, through which it can escape and entrain with it any air which may be present. Water is then forced up from the tank, by the pressure of the atmosphere upon it, and into the mixing tube, where the injector action takes place as with the non-lifting injector.

The lifting action may be started either by hand control or by an automatic device. In the hand controlled type the size of the steam jet, J, on Pl. **106**, Fig. 2, is controlled generally by a cone-valve, C, and when first started it only opens slightly. The amount of steam entering is then so small that after it has expanded it can still escape easily by the overflow vents, O. Water having been drawn in, as indicated by water pouring from the overflow, the jet can be fully opened and the water supply adjusted till neither water nor steam escapes.

3. **Automatic injectors.**—These have some device, such as a large extra overflow valve, Q, or a split mixing tube, so that when steam is first turned on it can lift the valve or spread the split tube and so escape freely. *See* Pl. **106**, Fig. 2.

As soon as a partial vacuum has been formed, *i.e.* as soon as the pressure is well below atmospheric, the valve or tube closes automatically, and simultaneously water rises through the supply pipe, W. The injector then works normally.

Automatic injectors are necessary for locomotives if the feed water is to be lifted, because the action of a lifting injector is liable to be stopped by jolting, in which case it must be started afresh.

Lifting injectors cannot be made to work satisfactorily with exhaust steam.

4. **Feed pumps.**—When boilers are fed with water returned from a condenser, the temperature of the water is usually too high for the use of an injector. Such boilers are, therefore, supplied by feed pumps. Feed pumps are of four main varieties, viz. :—

- i. Simplex or duplex type of double-acting steam pump, which is simple but rather uneconomical in steam.
- ii. The eccentric-driven ram pump, driven from the main crankshaft.
- iii. Three-cylinder ram pumps, driven by electric motor.
- iv. Rotary pumps, normally electrically driven.

5. In the *simplex type*, diagrammatically shown on Pl. **106**, Fig. 3, the steam is admitted to the steam cylinder by a slide valve, which is thrown over at the end of each stroke by a small auxiliary piston working in an auxiliary cylinder, A, to which steam is admitted just before the end of a stroke by means of a tappet, T, and stop on the main pump rod, which moves the auxiliary valve.

In the *duplex type* there are two rods, each with its own piston and cylinder, to which steam is admitted by a slide valve. Each slide valve is moved across by the movement of the other piston, so that the rods make strokes alternately.

An eccentric-driven ram pump worked by the main shaft is economical, but cannot be fitted alone, since it cannot be operated when the main engine is stopped.

Electrically-driven three-cylinder ram pumps are economical where electrical energy is easily obtained. Their action is smooth and their rate of delivery is easily controlled.

Electrically-driven centrifugal feed pumps are the best type for large installations. Their efficiency is high and their delivery smooth and flexible.

6. **Position of feed pumps.**—It is essential that feed pumps should be run flooded, *i.e.* that water should flow into them by gravity. Since the water is hot, its vapour pressure approximates to that of the atmosphere, and, therefore, the suction is liable to fail if the pumps are made to lift from tanks at a lower level.

7. **Temperature limits.**—Since it is essential for the suction of a pump of any description that the vapour pressure of the water shall not exceed that of the atmosphere, feed pumps must be installed so that they draw water from feed tanks open to the atmosphere, and may then be made to force the feed water through any feed water heaters and economizers by which the water is to be further heated before it is supplied to the boilers.

8. **Feed water valves.**—The rate of supply of feed water to each individual boiler should be controlled by means of a stop valve near the boiler. The valve should be within easy reach of the boiler attendant.

9. **Feed water regulators.**—To ensure a nearly constant level in a boiler and to eliminate the human element, several devices known as feed water regulators have been invented. Their provision also saves labour and consequently expense in wages.

They consist of a device for opening the feed water stop valve when the water level falls below normal, and closing it when the level has risen to normal.

CHAPTER XXIV

BOILER AUXILIARIES

120. *Nature and use of the common auxiliaries*

1. **Definition.**—An auxiliary is any device provided for improving the efficiency or ease of working of a boiler or set of boilers.

2. A chimney, fan, or other device for producing a good draught through the fire, which is necessary for all boilers, may be regarded as an auxiliary.

Other auxiliaries may or may not be considered necessary or desirable. Those in normal use are :—

i. Feed water heaters.
ii. Economizers.
iii. Superheaters.
iv. Automatic stokers.
v. Means for burning fuels other than coal or wood.
vi. Air preheaters.

3. It must be realised that the above are not essential, and in many cases their addition would not produce an improvement in efficiency proportionate to the increased cost of providing or working the plant. In small plants, the addition of unnecessary auxiliaries would often necessitate an increase in the staff required, and would seldom cause a proportionate saving.

In service plant, the necessity for simplicity and reliability is of more importance than extreme economy, and therefore few auxiliaries are used, except in the larger and comparatively permanent installations.

4. **Feed water heaters.**—A feed water heater, Pl. **106**, Fig. 5, utilizes some of the heat in the exhaust steam, which would otherwise be lost in the condenser, to heat the feed water to some extent before it passes to the economizer or boiler.

The exhaust steam is usually passed through a barrel in which are a number of tubes, through which the feed water is made to circulate.

5. **Economizers.**—An economizer utilizes some of the heat which remains in the flue gases after the boiler has extracted as much heat from them as is economically possible. Since the water in a boiler working at 150 lbs. absolute is at 358° F. it follows that the flue gases leaving it must still be well above that temperature. Therefore, the water, after it has left the feed water heater at perhaps 120° F., can absorb

a large amount of heat from these gases. It is not economical to cool down the gases below 300° F. before they pass into the chimney unless forced or induced draught is provided, because the chimney draught will be spoilt.

It is essential that the water shall be already at least at 100° F. before it enters an economizer; otherwise, moisture and acids from the flue gases would condense on the tubes and rapid corrosion would follow. This would be dangerous, since the economizer is usually under boiler pressure.

In practice, an economizer consists of banks of tubes placed in the flue, Pl. **106**, Fig. 6. Scrapers, S, are necessary to keep the tubes clear of soot and tar, and are generally driven by a small electric motor.

The efficiency of an economizer is much increased if the water is made to pass through a series of banks of tubes, passing first through those farthest from the boiler, *i.e.* where the gases are coolest, and lastly through those nearest the boiler.

An economizer adds about 1 per cent. to the efficiency of the boiler for every 15° F. through which it heats the feed water. Thus if the water leaving the feed water at 120° F. is delivered at 300° F., the saving is about 12 per cent.

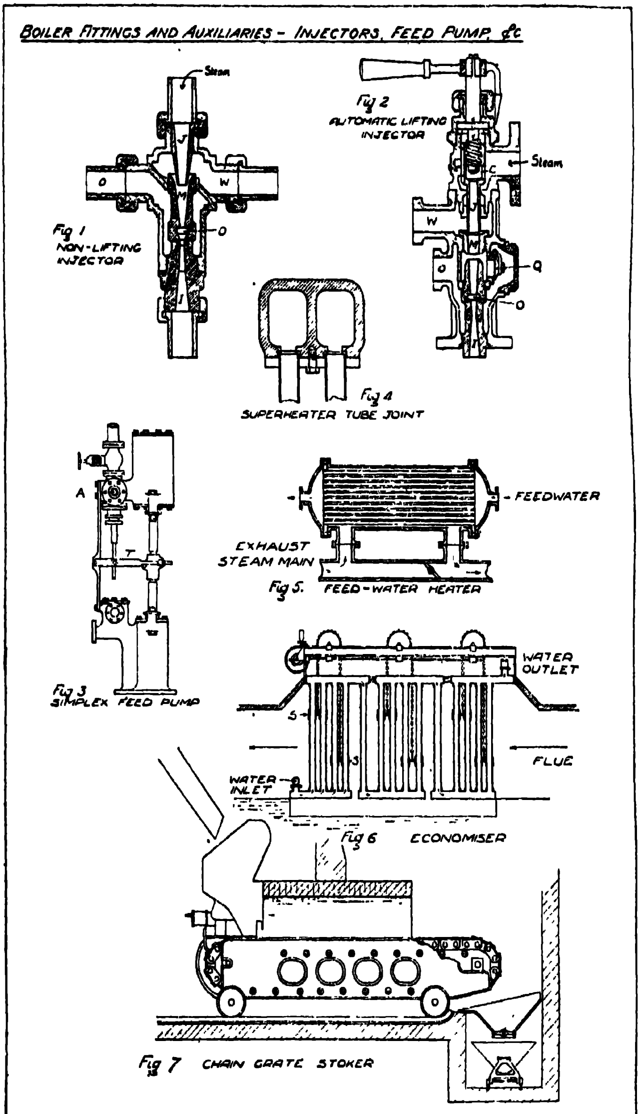
6. **Superheaters.**—Superheaters are used to dry the steam produced by boilers, and also to provide the steam with a little extra heat which it can lose during its passage to the engine cylinder without being reduced to its saturation temperature, and, therefore, without being partly condensed. An increase of 100° F. is generally sufficient for low pressures, but in large plants, especially for turbines, a gain in thermal efficiency is produced by passing the steam into the engines or turbines with a considerable amount of superheat.

To effect this, the steam is collected in the usual manner and is then passed through several tubes of solid-drawn steel, which are placed in the flue space of the boiler at a place where the gases are hot, but not directly above the grate, as shown on Pl. **96**, Fig. 3, and Pl. **98**, Fig. 1. In water-tube boilers the superheater is usually swept by the gases after they have already passed one bank of water tubes. In Lancashire and similar boilers, the superheater tubes are usually placed in the end chamber, where the gases have already passed through the central flues and have so lost some of their heat. In locomotive type boilers the superheater tubes are placed inside the flue tubes, some of which are enlarged for the purpose.

The tubes are generally separate, and each one is fixed into the head, or collecting chest, by means of a single stud, the joints being made of copper washers, Pl. **106**, Fig. **4**.

Since the tubes are only prevented from burning by the

PLATE 106.


BOILER FITTINGS AND AUXILIARIES - INJECTORS, FEED PUMP, &c
Steam
Fig 1
NON-LIFTING INJECTOR
Fig 2
AUTOMATIC LIFTING INJECTOR
Steam
Q
Fig 4
SUPERHEATER TUBE JOINT
A
Fig 3
SIMPLEX FEED PUMP
FEEDWATER
EXHAUST STEAM MAIN
Fig 5. FEED-WATER HEATER
WATER OUTLET
FLUE
WATER INLET
Fig 6 ECONOMISER
Fig 7 CHAIN GRATE STOKER

rapid transference of heat to the steam passing through, it is essential that some means should be provided for shutting off the gases from the tubes, at any rate partially, when steam is not being taken by the engine. In many cases this is effected by opening a bye-pass door, which allows the gases to take a shorter path to the chimney, D, on Pl. **96**, Fig. 3. In other cases the tubes can be flooded with water.

7. **Air pre-heater.**—A simple means of pre-heating the air to be drawn into a furnace is to guide the air across the face of the boiler, so that it absorbs the heat which would otherwise be radiated out into the boiler house (Pl. **102**, Fig. 6). In hot climates it also constitutes an effective method of reducing the temperature of the boiler room by stopping the radiation of heat from the boiler-face, which is otherwise very unpleasant for the attendants.

The ordinary air pre-heater contains large numbers of thin metal plates, which transfer heat from the outgoing furnace gases to the incoming furnace air. An air pre-heater is often better than an economizer for extracting heat from low temperature furnace gases. The increase in boiler efficiency is greater than would be obtained by the extraction of flue-gas heat; for owing to the higher furnace temperature obtained combustion is more complete.

121. *Automatic stokers and special grates*

1. **Automatic stokers** are intended to save labour, to eliminate the human element in firing, to produce more uniform temperature in the fire by continuous feeding without opening the doors, and to allow of the use of low-grade coal.

Stokers firing ordinary coal, work on one of two methods, viz.:—

i. Coking.
ii. Sprinkling.

2. **Coking process.**—The coking process is one in which coal is fed slowly into the grate, as, for instance, by a chain grate. The coal is first coked, its volatile constituents passing forward over the grate and being burnt there. (*See* Pl. **106**, Fig. 7.) As the coal is carried further into the furnace, it is gradually raised to incandescence and the carbon is consumed. When it reaches the back of the grate and falls over into the ashpit, nothing but ash should remain.

Other types force the coal into the grate by means of rams, and the fire is carried forward by movements of the firebars. Two or more groups of firebars are provided, with separate oscillating movement. The bars are so coupled that

all odd numbers move together backwards, and then all even numbers do likewise. In consequence, all the bars move backwards without moving the fire. The next step is that all the bars move forward together, carrying the fire with them, and complete the cycle. Thus the fire is slowly carried forward as on a chain grate.

3. **Sprinkling stokers.**—The sprinkling type of automatic stoker consists merely of a spring operated ram which throws very small quantities of coal on to the firebars, and whose stroke is varied by using various cams in succession, so that an even fire is maintained all over the grate. The firebars may also be oscillated to get rid of the ash.

4. **Handling of coal.**—The main object of every automatic stoker—the reduction of labour—can only be effected by providing an efficient system of hopper feed and coal hoist, so that the fuel is not man-handled at all. The coal must be broken small enough to descend freely through the hoppers.

5. **Pulverized fuel.**—A type of automatic firing which has been used largely in cement factories and is also highly efficient in its application to steam raising, is that known as pulverized coal firing.

Coal must have been dried, crushed and milled to impalpable powder before it can be described as pulverized.

Pulverized coal is usually fed by a screw conveyor, or some similar device, to a fan, by which it is suspended in a certain amount of air and the mixture forced into the furnace, where more air is added to ensure the complete combustion of the fuel. A large combustion space should be provided.

On account of the finely-divided state of the fuel, combustion is easily completed, less air need be passed into the furnace than for burning ordinary coal, no ordinary clinker can be formed, poor coal can be used economically, and black smoke is eliminated although a large proportion of the ash finds its way up the chimney.

The consumption of fuel can be quickly increased, decreased, or completely stopped at will.

In consequence of the hotter furnace gases, due to less dilution, and of the complete combustion of the fuel, the efficiency is very high.

6. **Refuse burners.**—The ordinary refuse of a town or barracks may be burnt to produce steam. It is usually difficult to ignite, its calorific value is low, and it may contain a large percentage of moisture.

Plant to consume such refuse includes generally a small grate upon which coal or coke is burnt with an excessive supply

of air. The hot gases from this grate, containing a high percentage of unused oxygen, are then passed through the larger grate, upon which the refuse is burnt. Any further air required to complete combustion is drawn in through passages in hot brick walls, so that it is delivered at a high temperature. The refuse is often dried on a dead plate before it is fed into the grate, so that it is fired in dry and hot.

It is essential, when burning refuse, whose combustion is liable to produce an objectionable odour, that all the vapour from the dead plate should pass through a hot fire, so that all organic vapours may be completely destroyed. In this case the refuse is first dried in a chamber kept hot by the flue gases, and burnt upon a grate, the temperature of which is maintained by the proximity of a small but hot coal fire, through which the gases from the refuse fire are passed to deodorize them.

Refuse containing a large percentage of easily burnt fuel, such as sawdust, bark, straw, &c., may be used on an ordinary grate, the fire being fed alternately with the refuse and with coal or coke. This system is not easy to work satisfactorily, since it is difficult to eliminate smoke, and the refuse is liable to be carried by the draught into tubes and flues.

122. *Natural, induced and forced draught*

1. **Natural draught** is produced by means of a chimney only.

The hot gases which pass from a boiler are lighter than air at ordinary temperatures, and, therefore, when a chimney is full of such hot gases, the pressure at the base is less than barometric pressure by the difference in weight between (*a*) the column of hot gases actually present in the chimney, and (*b*) a similar column of cold air of the same height. The flue gases contain less oxygen than ordinary air, but its place is taken principally by carbon dioxide, of which the quantity present is small, and the weight is not much affected.

A column of air (weighing 1 lb. per 13 cubic feet) of 1 square foot section and 100 feet high weighs normally 7·7 lbs. If it is heated from 60° F. to 350° F., which is normal chimney temperature, its weight per cubic foot is decreased in the ratio $\frac{459 + 60}{459 + 350}$, or to 64 per cent. of its weight at 60° F.

The column 100 feet high, therefore, weighs about 5 lb., and the difference in pressure is 2·7 lb. per square foot, or 0·019 lb. per square inch.

The draught of a chimney is generally measured by means of a gauge consisting of a U-tube containing a little water, one end of the tube being connected to the base of the chimney

by a pipe and the other open to the atmosphere. The difference in the level of the water in the two limbs is then measured. *See* Pl. **102**, Fig. 5.

Since water weighs about 63 lb. per cubic foot, a pressure of 2·7 lb. per square foot will cause a difference in level of $\frac{2 \cdot 7}{63}$ foot, or about $\frac{1}{2}$ inch.

In consequence of the difference in weight, the hot air in the chimney rises and is replaced by more flue gases from below, and the velocity with which it rises depends upon the difference in temperature inside and outside the chimney, and also upon its height. The theoretical velocity is expressed by the formula:

$$v = \sqrt{\frac{2gh(T_1 - T_2)}{491}}$$

v = velocity in feet per second.
h = height of chimney in feet.
T_1 = mean temperature of chimney gases in degrees F.
T_2 = outside temperature in degrees F.

In practice, the velocity is much reduced by air friction in the chimney and flues, and for this reason flues should be as short and straight as possible.

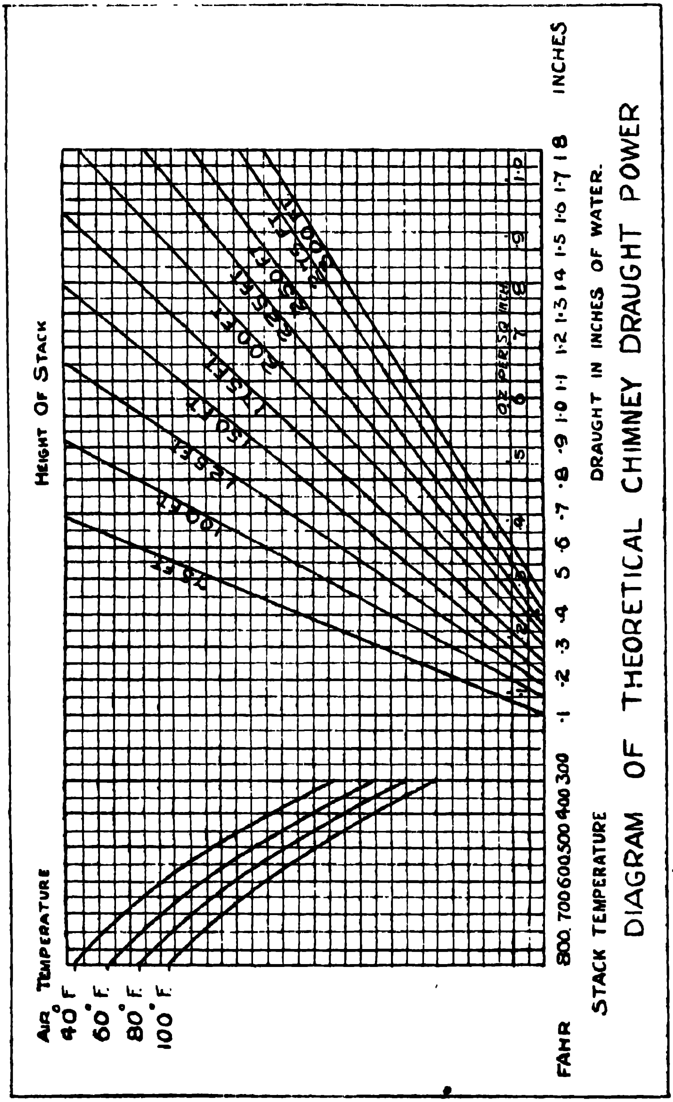
Pl. **107** shows the theoretical chimney heights for various temperature and draught conditions. In using this graph, allowance must be made in calculations for loss of draught by air friction in the flues. The flues should be about 30 per cent. larger in area than the chimney. Steam coal will normally burn well with $\frac{1}{2}$-in. draught or less, but coal dust needs at least $\frac{7}{8}$-in. draught.

Since the quantity of air rising through the chimney is the same as that going through all grates, leaks in brickwork, &c., it is obvious (*a*) that the brickwork should be painted or otherwise proofed, and any cracks carefully stopped to limit air leakage; and (*b*) that the area of the chimney should be large if good draught is required. In practice, it is usually from one-sixth to one-ninth of the grate area, and may with advantage be more.

In most cases an increase in the area of a chimney is better than a proportional increase in height. It is not economical to provide a chimney higher than 20 times its internal diameter, unless such a height is required to ensure that the gases are carried above any surrounding roofs or windows.

2. **Efficiencies.**—The energy supplied by a boiler having a definite grate area is directly proportional to the weight of coal burnt per hour, provided the efficiency of the boiler

PLATE 107.


HEIGHT OF STACK
AIR TEMPERATURE
40° F
60° F
80° F
100° F
FAHR
800 700 600 500 400 300
STACK TEMPERATURE
·1 ·2 ·3 ·4 ·5 ·6 ·7 ·8 ·9 1·0 1·1 1·2 1·3 1·4 1·5 1·6 1·7 1·8 INCHES
DRAUGHT IN INCHES OF WATER.
OZ PER SQ INCH
DIAGRAM OF THEORETICAL CHIMNEY DRAUGHT POWER

remains unaltered. Actually the efficiency can often be improved by increasing the rate of combustion, because the higher temperature on the grate makes it possible to burn the fuel more completely and with less diluting air. Consequently the furnace gases are hotter and can transfer a larger proportion of their heat to the boiler.

The weight of coal which can be efficiently burnt on the grate with natural draught varies from 10 to 12 lbs. per square foot of grate area for boilers of vertical type to 15 to 20 lbs. for Cornish and locomotive type boilers.

The efficiency of a boiler in heat transference is represented by $\frac{T_1 - T_2}{T_1 - T_0}$, where T_1 is the temperature of the furnace gases, T_2 that of the flue gases after leaving the boiler, and T_0 that of the atmosphere. This formula may be expressed as

$$\frac{\text{heat given by gases to the boiler}}{\text{heat produced by burning fuel}}.$$

The use of a powerful draught, and the consequent rapid combustion of fuel with less diluting air, may increase T_1 considerably, since the theoretical temperature produced by burning coal with only the absolutely necessary amount of air is nearly 4,000° F., whereas in normal practice, in which nearly double the requisite amount of air passes through, the temperature attained is only about 2,500° F.

By the use of large, well-designed economizers and air pre-heaters T_2 may be kept low.

3. **Artificial draught.**—To produce a powerful draught by means of a chimney alone necessitates a large outlay in capital, since great height and cross-sectional area are necessary. Moreover, the advantage of a large chimney is lost unless the gases are liberated to it while still at a fairly high temperature. By forcing air through the grates by mechanical means any desired rate of combustion can be achieved, and no limit is placed upon the temperature to which the gases may be reduced by the economizer. The chimney need then only be high enough to carry the fumes clear of neighbouring buildings, or to comply with local regulations.

Induced draught is produced by placing a fan or a steam jet at the base of the chimney. The exhaust of locomotives may thus be utilized to produce a draught of 8 inches water gauge, and so to burn 120 lbs. of coal per hour per square foot of grate area.

Forced draught may be produced by fitting a fan to blow air into the furnace below the grate. A steam jet may also be used for this purpose. In some ships the pressure in the stokehold is raised by forcing air into it by means of a fan.

To increase T_1 still farther, the air is first passed over tubes through which outgoing flue gases are passed. In consequence, the air enters the furnace already raised to 250° F. About 80 lbs. of coal per hour can thus be burnt per square foot of grate area.

Balanced draught, which comprises both induced and forced draught, is frequently employed in large power stations, as by this means a very accurate control of the draught can be obtained.

CHAPTER XXV

RECIPROCATING STEAM ENGINES

123. *Introduction*

1. A simple single-cylinder reciprocating steam engine is shown on Pl. **108**, Fig. 1. It consists essentially of a *piston* connected by a piston-rod to a *crosshead* C, which is guided between fixed *guide bars* B. If, as is usual, the engine is double-acting, a *stuffing box* S must be used to prevent leakage of steam past the piston-rod. A *connecting-rod* connects the *gudgeon pin* G in the crosshead to the *crank pin* P.

In a double-acting steam engine, when the steam has pushed the piston up to one end of the cylinder it is exhausted to atmosphere or to a condenser, and fresh steam is admitted to the other side of the piston to perform the return stroke. The admission and exhaust of steam at the right moments and for the desired periods is effected by mechanically operated valves (*see* Sec. **130**).

2. **The cycle of operations and ideal indicator diagram.**—Pl. **109**, Fig. 1, is the ideal graph connecting the pressure and volume of the steam at one end of the cylinder during a cycle of operations. Starting at the point *a*, which is the beginning of the working stroke, steam at full boiler pressure enters the cylinder and pushes the piston away until point *b* is reached, when the admission valve closes. A volume of steam, *ab*, is therefore trapped in the cylinder and expands, the pressure and temperature falling as represented by the curve *bc* ; the point *c* marks the pressure and volume at the end of the piston stroke. At *c* the expanded steam at low pressure and temperature is free to escape to atmosphere or condenser. During the return of the piston, *i.e.* *c* to *d*, the pressure remains constant at atmospheric or condenser pressure whilst the used steam is being expelled. At *d* the steam admission valve is again open and the boiler immediately supplies new steam, bringing the pressure up to *a* again, whence the cycle is repeated. *b* is called the point of " cut-off."

124. *Elementary thermodynamics of the steam engine*

1. In Pl. **109**, Fig. 1, *ab* represents the evaporation (and superheating, if any) of the steam *bc* expansion, *cd* condensation, and *da* the heating of the water in the boiler.

   i. If the steam is initially dry at the point *b*, and the expansion is *adiabatic*, then the equation to the curve *bc* is $P.V.^{1\cdot135} =$ constant.

Plate 108.

RECIPROCATING STEAM ENGINE DETAILS.

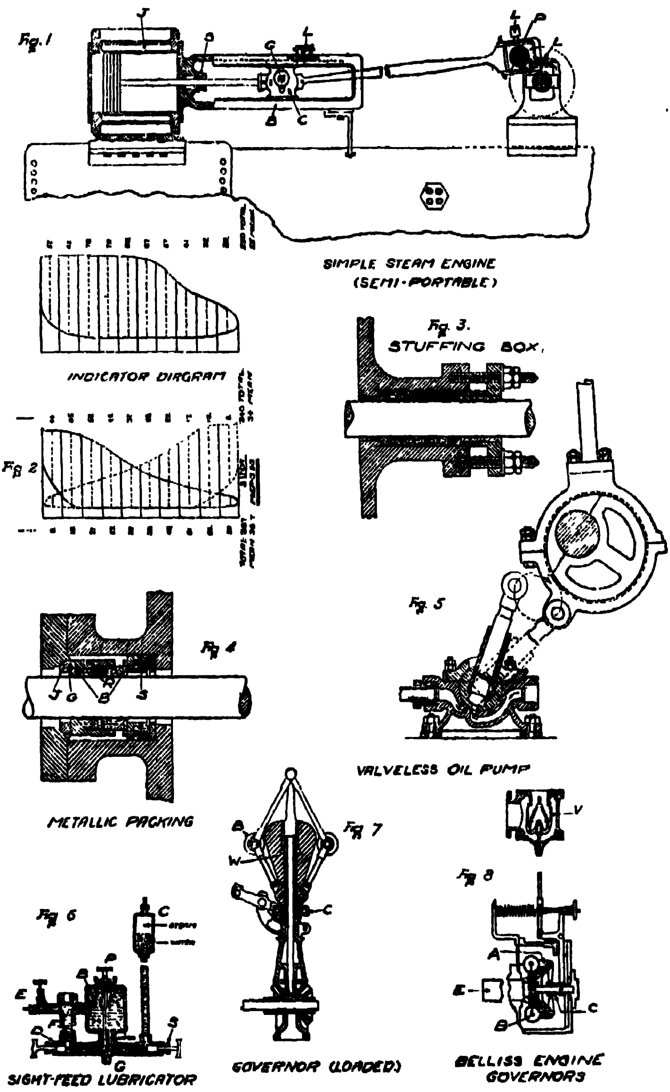
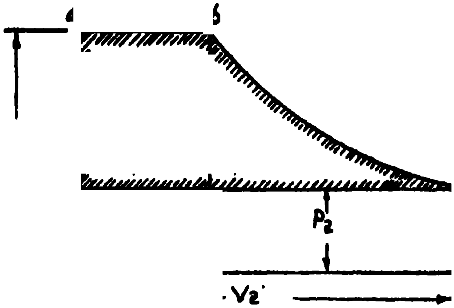


PLATE 109.

STEAM ENGINE DIAGRAMS.



g.1. Theoretical P.V. Diagram.

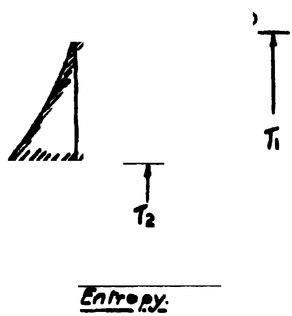


Fig 2. Theoretical Tφ diagram.

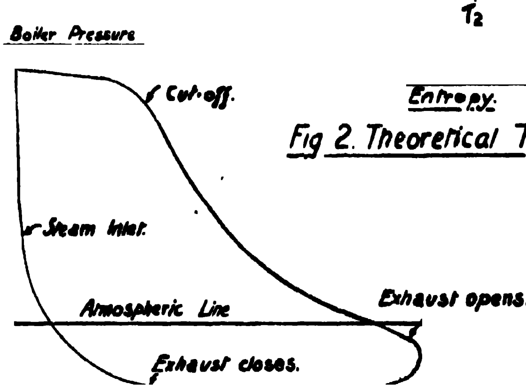


Fig. 3. Typical steam indicator diagram from a Single Cylinder Condensing Engine.

ii. If the steam remains dry and saturated throughout the expansion, then $P.V.^{17/16} =$ constant.

iii. Assuming hyperbolic (isothermal) expansion we get $P.V. =$ constant.

These curves are shown in Pl. 94, Fig. 2.

The actual expansion curve is probably between those for dry saturated steam and for isothermal expansion as shown at AC in the figure.

2. **Rankine cycle.**—When the expansion is *adiabatic* the cycle is called the *ideal Rankine cycle.* This is employed as a standard of reference with which the performance of steam engines may be compared, *cf.* the air standard cycle used for I.C. engines.

3. **Efficiency of the Rankine cycle.**—In any heat engine, the *theoretical thermal* efficiency $= \dfrac{\text{heat turned into work}}{\text{heat supplied}}$.

The efficiency of the Rankine cycle equals :—

i. *For saturated steam*—

$$\frac{Q_1 - Q_2}{Q_1 - Q_{w2}} = \frac{(T_1 - T_2)\left(1 + \frac{L_1}{T_1}\right) - T_2 \log_e \frac{T_1}{T_2}}{L_1 + T_1 - T_2}.$$

ii. *For superheated steam*—

$$\frac{Q_s - Q_2}{Q_1 - Q_{w2}} = \frac{(T_1 - T_2)\left(1 + \frac{L_1}{T_1}\right) + 0{\cdot}48(T_s - T_1) - T_2\left(\log_e \frac{T_1}{T_2} + 0{\cdot}48 \log_e \frac{T_s}{T_1}\right)}{L_1 + T_1 - T_2 + 0{\cdot}48(T_s - T_1)}$$

Q_s = total heat of superheated steam at stop valve.
Q_1 = ,, ,, saturated steam at stop valve.
Q_2 = ,, ,, water and steam at exhaust.
Q_{w2} = ,, ,, water at exhaust.
T_s = absolute temperature of superheated steam at stop valve.
T_1 = absolute temperature of saturated steam at stop valve.
T_2 = absolute temperature of water and steam at exhaust.
L_1 = latent heat of steam at T_1.
0·48 = assumed specific heat of superheated steam.

4. **Entropy.**—When a substance takes in or rejects heat it is said to change its *entropy*. The change of entropy is defined by the expression $d\phi = T.dQ$, entropy being denoted by ϕ. Each increment (or decrement) of entropy $d\phi$ is equal to the quantity of heat dQ taken in or rejected, multiplied by the absolute temperature, T, of the substance.

It can be shown that if a curve be drawn with T and ϕ as ordinates, the area under the curve is equal to the whole quantity of heat taken in while the substance passes through the states which that portion of the curve represents. This is a useful alternative to the P.V. diagram method of representing heat-engine performance.

In *isothermal* change we are dealing with change of entropy at *constant temperature.*

In *adiabatic* change we are dealing with change of temperature at *constant entropy* (for this reason adiabatics are sometimes called *isentropics*).

Therefore, in a $T\phi$ diagram isothermals will be lines parallel to the axis of entropy, and adiabatics will be lines parallel to the axis of temperature.

The $T\phi$ diagram for the Rankine cycle is shown in Pl. **109**, Fig. 2. With the same notation as used on the corresponding P.V. diagram shown in Fig. 1, *ab* is the change of entropy which the substance undergoes in passing from water to steam at the constant temperature $T_1(ab = \frac{L_1}{T_1}$; assuming the evaporation to be complete, *bc* represents *adiabatic* expansion to T_2 corresponding with the back pressure P_2, *cd* the process of condensation, and *da* the heating of the feed water from T_2 to T_1, which completes the cycle.

In both diagrams the area *abcda* represents the work done in the cycle (see note on page 501).

5. **Total heat-entropy diagram.**—Still making use of the very useful conception of entropy, we can construct a diagram with axes of *total heat*, and entropy, and we then get the most useful diagram for use in calculations on the performance of steam engines and turbines.

Such a diagram, known as a *Mollier* diagram, is given in Pl. **110.** The diagram has three principal uses :—

i. Steam total heat can be read off for any condition.
ii. During adiabatic expansion, the entropy of steam remains constant ; the diagram will therefore show the steam conditions at the end of such an expansion by following the appropriate vertical entropy line until it meets the exhaust pressure line. The appropriate entropy line is discovered from the point on the diagram which shows the pressure and superheat conditions at the beginning of expansion. The quality of steam is the proportion of dry steam in a mixture of steam and water.
iii. The gain in superheat or dryness on throttling is discovered by following the appropriate constant total heat line. The total heat in steam remains constant during throttling to a lower pressure.

6. As an example of the use of this diagram, suppose the stop-valve pressure to be 220 lb./sq. in. absolute, superheat, 140° F., and the condenser pressure 4 in. of mercury (say 2 lb./sq. in. absolute).

From the Mollier diagram :—

i. Total heat of superheated steam at 220 lb./sq. in., 140° F. superheat = 1,280 B.Th.U. (Point A).

ii. Total heat of wet steam at 2 lb./sq. in. = 940 B.Th.U. (Point B vertically below point A on line of *constant entropy*. Note that about 17 per cent. of the steam is condensed at the point B).

iii. Water heat of condensed steam (Table W, page 439) = 94 B.Th.U.

The *available heat* = 1,280 − 940 = 340 B.Th.U.
The *heat supplied* = 1,280 − 94 = 1,186 B.Th.U.
The *Rankine cycle efficiency* $= \frac{340}{1,186} = 0{\cdot}286.$

The steam consumption per I.H.P.-hour of the ideal engine would be $\frac{2,545}{340} = 7{\cdot}5$ lb.

125. *Practical efficiencies*

1. The thermal efficiencies realized in practice do not exceed 50 to 75 per cent. of the ideal Rankine cycle described above, this percentage being known as the *efficiency ratio.*

Suppose that an actual engine working under the above conditions consumes 11·5 lb. of steam per I.H.P., then the *efficiency ratio* $= \frac{7{\cdot}5}{11{\cdot}5} = 0{\cdot}65.$

The *indicated thermal efficiency* = 0·286 × 0·65 = 0·186, or 18·6 per cent.

If the *mechanical efficiency* is 90 per cent.,
the *brake thermal efficiency* = 18·6 × 0·9 = 16·74 per cent.

2. The main reasons for the difference between ideal and indicated thermal efficiencies are :—

i. The valves do not open nor close instantaneously. This rounds off the corners of the diagram.

ii. The expansion is not complete, nor adiabatic, because of the heat exchange between the steam and the cylinder walls.

iii. There is compression at the end of the exhaust stroke because the valve closes before the end of the stroke. (Sec. **130**, para. 5.)

iv. There is a certain amount of clearance volume in the cylinder when the piston is at the end of the stroke.

Examples of actual indicator diagrams are shown on Pl. **108**, Fig. 2, and Pl. **109**, Fig. 3.

3. The power developed by a steam engine may be increased by :—

i. Increasing the initial pressure of the steam.
ii. Causing the cut-off to take place later, and, therefore, using more steam.
iii. Reducing the back pressure during the return stroke.
iv. Speeding up the engine.

4. It is difficult to effect much improvement in any existing engine, because :—

i. The pressure available is generally limited by the strength of the boiler available, if not by the design of the engine.
ii. A late cut-off reduces the efficiency of the engine.

It is possible, however, to effect a considerable improvement by making the cylinder exhaust into a condenser, in which a good vacuum is maintained.

The speed of an engine can seldom be much increased above that for which it was designed without causing vibration and increased stresses which may be dangerous.

5. **Practical economy.**—The best results will generally be obtained by a careful attention to detail, allowing the engine to operate precisely as intended by the designer, and ensuring that steam is not wasted through leaking joints, piston-rings, &c., nor power wasted through unnecessary friction in piston, piston-rod, or bearings.

The performance of an engine during the maker's test is seldom achieved in actual working. In estimating the boiler capacity necessary to feed an engine, this must be taken into consideration. The consumption during normal working must be expected to be 25 per cent. more than that of the maker's full-load test under ideal conditions.

Table X, on page 539, shows sample figures for various types of engine as obtained during makers' tests, giving lbs. of steam per B.H.P.-hour.

6. **Effect of variation in load.**—It will be seen from Table X that the consumption of steam per B.H.P.-hour increases as the load upon an engine decreases. The reasons are :—

i. Frictional losses are approximately constant at all loads.
ii. Steam leakages continue as at full load.
iii. Clearance spaces must be filled with steam, whatever the load.
iv. If cut-off governing only is employed, the greater range of expansion is frequently counterbalanced by the increased cylinder condensation which will occur with a large temperature change. Throttle governing, however, reduces this condensation loss by its superheating effect on the steam.

It is, therefore, important that as far as possible an engine shall work at nearly full load all the time, and when the load is fairly constant the engine should be chosen to ensure this.

7. **Overloads.**—It is generally possible to put a load 25 per cent. above the normal on to a throttle-governed steam engine, and up to 50 per cent. or more on to one governed by variable expansion, with a small loss in efficiency and with increase in wear and tear if applied for long periods.

Such overloading is not possible with I.C. engines.

126. *Cylinder condensation*

1. Condensation in cylinders is a large source of waste of steam in engines.

When hot steam is admitted to a cold cylinder, part of it is condensed to water upon the walls and piston. While steam is being admitted, the water remains in a film upon the metal and does no work. During expansion it partly re-evaporates as the pressure falls and does some work on the piston. In evaporating it cools down the walls again, so that more steam is condensed at the next admission. The efficiency of an engine is thus considerably reduced.

The greater the degree of expansion the larger is the variation in temperature, and, therefore, the amount of condensation.

Condensation may be diminished in several ways :—

i. The engine may be run faster to allow less time for condensation to take place.

ii. The cylinder may be surrounded by a jacket, J, on Pl. **108**, Fig. 1, containing live steam and lagged. Condensation in the cylinder is thus diminished.

iii. The ratio of expansion may be kept small in any one cylinder by using the steam successively in two or more cylinders of increasing diameter.

An engine is said to be *compound* when two such cylinders are used, the smaller one taking steam at boiler pressure, expanding it to a limited extent, and then exhausting it into the larger one for further expansion, Pl. **114**. A triple-expansion engine has three cylinders, the third one being larger still.

iv. The steam, after it has left the boiler, may be superheated or raised considerably in temperature, but not in pressure, by passing it through tubes in the boiler flues, Pl. **96**, Fig. 3, and Pl. **98**, Fig. 1. It has then some spare heat which it can expend in heating up the cylinder walls, valves, &c., without being cooled below its saturation point, and so none is condensed.

v. The engine may be designed to give a temperature gradient down the cylinder as in the *Uniflow* engine. (*See* Sec. **131** and Pl. **113**, Fig. 1.)

127. *Engine details*

1. **Stuffing boxes.**—Steam is prevented from leaking past the piston-rod by means of a stuffing box closed by a gland. For low-pressure steam the stuffing box is generally packed with asbestos rope, which is impregnated with tallow and coiled round the rod, Pl. **108**, Fig. 3.

The gland must only be screwed down hard and evenly enough to stop any escape of steam. If it were too tight the rope would grip the rod, a large amount of power would be wasted in friction, and, consequently, the rod would be heated and wear very rapidly.

Piston rods are liable to wear unevenly, and so become fluted. When this has occurred it is impossible to keep the glands tight enough to fill the grooves, and steam escapes.

2. **Metallic packing.**—For high-pressure steam and for superheated steam, metallic packing is necessary. This consists of several segment rings of anti-friction metal, R, on Pl. **108**, Fig. 4, held in place by a spring, S, and coned bronze hoops, B, or else by garter springs. The segments are arranged to break joints, so that steam cannot blow through them. Provision is made in metallic packings, and sometimes in rope-packing glands, for lateral play and swivelling, in case the piston rod should not be straight or the bore and guides out of line. A truly ground surface, G, provides for lateral movement without allowing steam to escape, while a spherical joint, J, carefully scraped to fit, and then ground in, allows for swivelling.

128. *Governing of steam engines*

The principles of governing explained in Sec. **71** in connection with I.C. engines apply equally well to steam engines. The governor controls the steam supply by varying the opening of the throttle valve, by altering the point of cut-off, or by both methods simultaneously.

Governors should be either mounted upon the engine shaft or driven by positive gearing. The obsolescent method of driving by belt is dangerous and unreliable.

A weight-loaded governor is shown in Pl. **108**, Fig. 7, and a spring-loaded shaft governor in Pl. **108**, Fig. 8.

129. *Lubrication of steam engines*

1. The lubrication of reciprocating steam engines is carried out by similar methods to those employed in I.C. engines. *See* Sec. **72**.

2. In high-speed vertical steam engines of the single-acting Willan's type (seldom met with nowadays) splash lubrication was used, but in the double-acting type such as the Bellis and Morcom, and Browett-Lindley, forced lubrication is generally employed.

Pl. **108**, Fig. 5, shows an oil pump.

3. For the valves and cylinders, mechanical force feed lubrication is usual in modern engines (*see* Sec. **72**), but on some of the older engines a sight feed lubricator worked by steam pressure may be met with. Pl. **108**, Fig. 6.

The barrel is prepared for filling by closing the steam valve S, and delivery valve E, opening the top plug P, and draining out the water. After filling the barrel B with oil, on closing plug P and opening valve S, steam enters the condenser C, is therein condensed and passes slowly into the barrel B, forcing out the oil through the regulating valve D, and so through the sight-tube F, which contains water. The oil rises in large drops, from the frequency of which the rate of feed can be judged, and adjusted by means of the regulating valve D, to that specified by the makers, which may be from one drop per minute upwards.

4. There are a few points in connection with the lubrication of cylinders and valves which are peculiar to the steam engine. The oil may in some cases be applied direct to the cylinder wall as in I.C. engines, but it is preferable to introduce it into the centre of the main steam-pipe, several feet from the main throttle, through a nozzle of special design, where the oil is atomized and carried along with the steam to lubricate both valves and cylinders.

In small types of vertical engines it may be found practicable to dispense with oil and rely upon the water present in the steam for the lubrication of valves and cylinders. This will mean some 10 to 20 per cent. increase in steam consumption due to increased friction losses and to leakage of steam past the piston, but in the case of condensing engines it ensures that no oil gets into the boiler.

Pistons of vertical steam engines really need very little lubrication as there is practically no side pressure, and the same remark applies to piston valves and balanced *D* slide valves.

In the case of the ordinary *D* slide valve, however, the pressure between the rubbing faces is considerable and very good lubrication is necessary.

5. Moisture in steam tends to wash pure mineral oil away from cylinder walls. This can be obviated in non-condensing engines by using a slightly (5 per cent.) compounded oil which tends to emulsify, cling to the cylinder walls and resist the washing action of the wet steam. In condensing engines, however, it is better to use a pure mineral oil, as it is difficult to separate the fatty oils from water.

Pure mineral oil is also best with superheated steam, which tends to decompose the fatty oils.

Ref. page 495.

The *isothermal* P.V. curve is the simplest to construct, and as it coincides approximately with that obtained in practice, it is frequently used in calculations.

Assuming PV=constant, therefore, for the *expansion curve* *bc*, the area *abcda* in Fig. 1

$$= P_1V_1\left(1 - \log_e\frac{V_2}{V_1}\right) - P_2V_2.$$

If P is in lbs. per *square foot*, and V in cubic feet, the result gives the nett work done in *foot lbs.*

The *mean effective pressure* $P_m = P_1 \frac{1 - \log_e r}{r} - P_2$, in which

$r = \frac{V_2}{V_1} =$ *expansion ratio* and $P_2 =$ *back pressure.*

For Bibliography, see page 689.

CHAPTER XXVI

VALVE GEARS

130. *The slide valve and expansion gears*

1. **The D slide valve.**—The slide valve is primarily a plate or cover which slides to and fro over ports in the face of a cylinder casting, and so opens and closes these ports to admit steam and cut off the supply. It also places these ports during the return stroke of the piston in communication with a passage to the atmosphere, or the condenser (if one is used), through which the used steam can escape.

The elementary D slide valve, D on Pl. **111**, Fig. 1, has faces of the same width as the cylinder ports, P, so that it just closes them completely when in the centre of its travel. In use it is central when the piston is at the end of its stroke at either end, and during a stroke it is traversed so as to admit steam from the chest in which it works to the working end of the cylinder, and at the same time to allow the steam to escape from the other end of the condenser through passage, E.

A slide valve is normally operated by an eccentric, X, upon the main shaft, S, of the engine, through rods, R. The eccentric is, in principle, merely a crank of short radius; *see* Pl. **108**, Fig. 5. In order to bring the valve central when the piston is at the end of its stroke, or on the *dead centre*, the eccentric must be set at right angles to the main crank, and in order to admit steam to the desired end of the piston it must be placed so as to precede the crank. It is then said to have 90° advance upon the crank, or to be at a 90° setting.

Such a valve admits steam during the whole stroke.

2. **Outside lap.**—To cut off steam before the end of a stroke, and so use it expansively, the valve is made to overlap the ports slightly on the outside when central. The valve must now move slightly before it can admit steam, and in returning will cover the port sooner than before, Pl. **111**, Fig. 2. To admit steam at the dead centre, the eccentric must now be turned so as to have more than 90° advance on the crank, possibly as much as 110°.

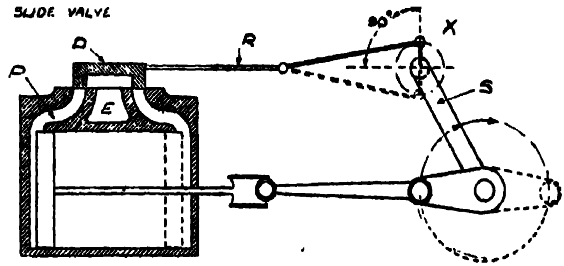
3. **Lead.**—In order that full steam pressure may act on the piston as soon as it begins to move, the eccentric is given still more advance. The amount by which the port is open at *dead centre* is called the *lead of the valve*, Pl. **111**, Fig. 3.

4. **Angle of advance.**—The total angle by which the eccentric is set in advance of the elementary 90° setting is known as the *angle of advance*, A on Pl. **111**, Fig. 3.

PLATE 111.

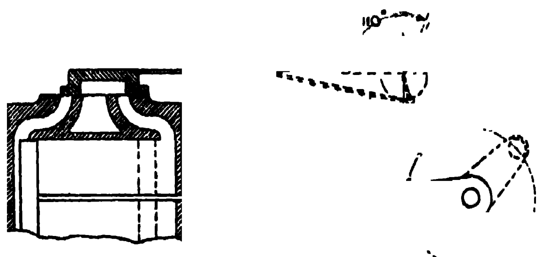
DIAGRAMS OF SETTING OF SLIDE VALVE.

Fig. 1



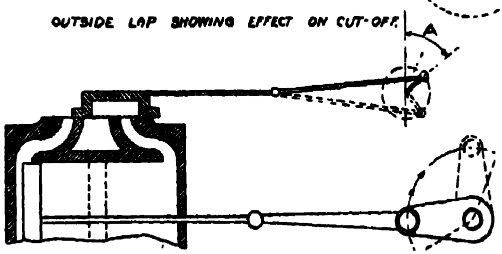
90° SETTING

Fig 2



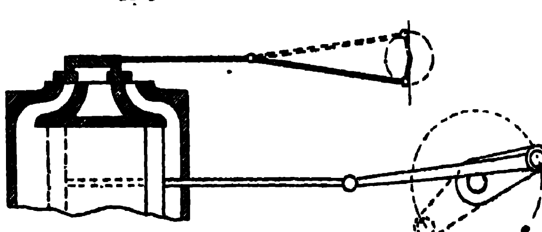
OUTSIDE LAP SHOWING EFFECT ON CUT-OFF

Fig 3.



WITH LEAD

Fig 4



INSIDE LAP SHOWING EFFECT ON EXHAUST

5. **Inside lap.**—In order to provide a cushion of steam to check the movement of the piston and its rods when approaching dead centre, it is usual to provide inside lap also. This causes the valve to close the ports during exhaust well before dead centre, and so imprisons a little steam in the cylinder, Pl. **111**, Fig. 4. It also causes the exhaust to open a little later, and so compensates slightly for the large angular advance necessitated by lap and lead, which is otherwise inclined to cause too early exhaust.

6. **Balanced valves.**—In old engines the slide valve is of the simple D form. In modern engines its place is usually taken by either a balanced valve or a piston valve, thus obviating the enormous pressure which a plain D valve must carry, especially in high-pressure cylinders.

A balanced valve may be of two types :—

i. It may consist of a box without bottom or top, provided on the back with a ring, R, on Pl. **112**, Fig. 1, which makes a steam-tight joint with the steam-chest cover. The only pressure upon the valve is then that which bears upon the outside lap.

ii. It may consist of an ordinary D slide, fitted with a relief ring on the back, the space enclosed by this ring being placed in communication with the atmosphere or condenser through a hole in the steam-chest cover.

7. **Piston valves.**—Pl. **112**, Fig. 2. A piston valve consists of a spindle, S, carrying two pistons, P, the thickness of each being the width of a face of a slide valve, *i.e.* width of a port plus outside and inside lap.

It slides in a cylinder which takes the place of a steam-chest ; live steam may be introduced into the ends, and the space between the pistons connected to the air, condenser, or intermediate chest for exhaust. This arrangement is often reversed, live steam being admitted to the central space, and the ends open to exhaust. *See also* Pl. **114**.

Each of the two pistons slide in a liner or bush, L, in which are the ports, arranged in a ring and opening into a passage which completely surrounds the liner. Thus pressures are absolutely balanced, and the amount of movement of the valve may be large without causing overheating, excessive wear, or absorbing much power. Moreover, the pistons may be placed far apart, so that the passages to the cylinder may be short and straight.

8. **Stephenson's link motion.**—When an engine is required to reverse, two different eccentrics are necessary, placed as shown on Pl. **112**, Fig. 3.

PLATE 112.

FORMS OF VALVES AND VAL

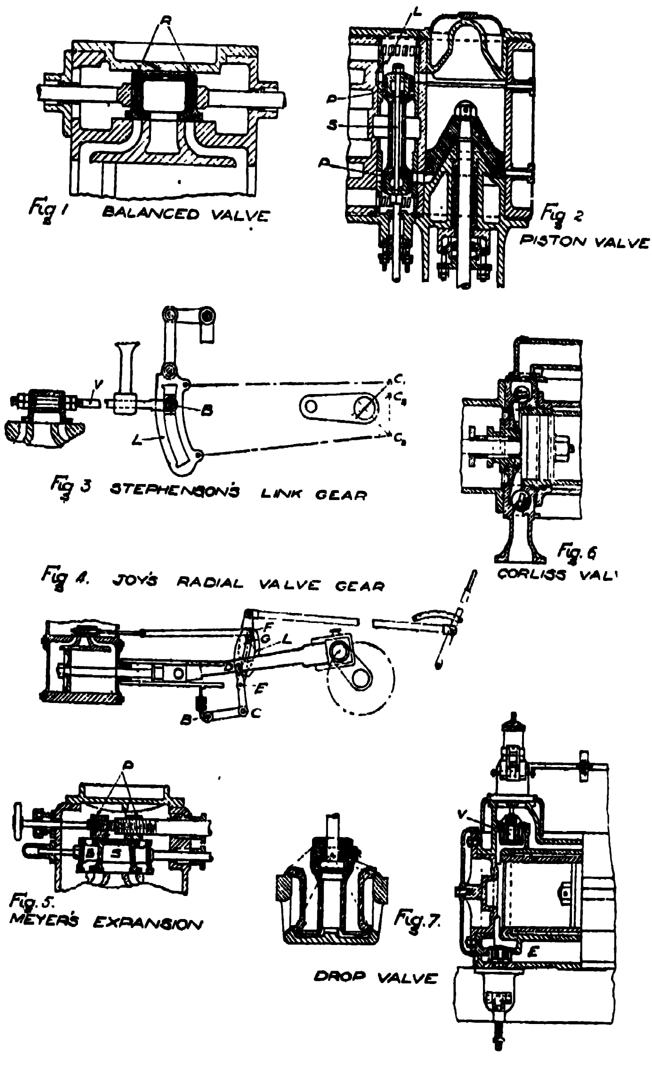


Fig 1 BALANCED VALVE

Fig 2 PISTON VALVE

Fig 3 STEPHENSON'S LINK GEAR

Fig 4. JOY'S RADIAL VALVE GEAR

Fig. 5. MEYER'S EXPANSION

Fig. 6 CORLISS VAL'

Fig. 7. DROP VALVE

Starting with both at right angles to the crank, when lap and lead are applied they cause the centre of both eccentrics to move away from the crank pin. Both eccentrics carry straps and rods which are coupled to a link, one at each end.

The block, B, on the valve rod, V, may be made to follow the movements of either eccentric by raising or lowering the link, L. In any intermediate position the valve is partly controlled by both eccentrics simultaneously. The effect is then approximately the same as though the valves were operated by one eccentric whose centre was some point on the line C_1C_2, such as C_3. Such an eccentric would cause the same amount of valve opening at dead centre as either of the actual eccentrics, but would give less valve travel and a greater angular advance.

The final result is the same whether the rods are *open* (the more usual arrangement) or *crossed* as shown in Pl. **112**, Fig. 3.

(It will be noted that in this figure the crank is inside the links. The term *open and crossed* are applied to the arrangement of the links when the crank is *outside* the links, *i.e.* 180° from the position shown.)

When the link is *notched up* (*i.e.* the block B moved towards the mid-position), with *open* rods, the lead increases and the valve therefore opens earlier; with *crossed* rods the reverse happens. In both cases, however, the valve opens less and remains open for a shorter period. The steam is, therefore, admitted for a shorter period of the stroke, and works expansively to a greater ratio.

Less power will then be developed, since the mean effective pressure is less, but better economy will be obtained, since much less steam is admitted.

There are many varieties of the link gear, some having straight links; in these both link and block are moved in opposite directions in notching up, to overcome any tendency to alter the total length of the rods.

9. **Radial valve gears.**—In locomotives, eccentrics take up valuable space on the crankshaft. Hence the introduction of radial valve gears, such as that shown on Pl. **112**, Fig. **4**, in which motion is obtained from a point on the connecting rod, through two linked rods, BC and CD, and a floating lever, EG, whose extension, GF, moves the valve rod through the distance required for lap and lead only.

The vertical movement of the point E, as the linked rods rock, raises and lowers G, which runs in a guide link, L. The angle at which the guide link is set controls the amount of port opening and the direction of rotation.

10. **Limits of expansion in slide valves.**—The slide valve does not work satisfactorily if made to cut off much before half-stroke, since the exhaust is also affected if much lead is given; and inside lap, in preventing too early an opening to exhaust, causes a very early closing and excessive cushioning or great back pressure.

11. **Meyer expansion gear.**—The Meyer expansion gear, Pl. **112**, Fig. **5**, consists of a plate, P, sliding on the back of a main slide valve, S, which has extensions, so that ports, B, are formed in it through which steam can enter the cylinder only when they are in line with the cylinder ports, and also uncovered by the plate or *expansion valve*, which is moved by an eccentric set opposite to the crank, or nearly so.

The main valve, S, is set to admit steam during the greater part of the stroke, and to exhaust as desired. The length of the expansion plate, P, may be variable, and it may be controlled by a right- and left-handed screw, operated from outside the steam-chest, or its travel may be altered by means of a slotted link. When the two plates are screwed farther apart, the effect is the same as though a wider single plate were used, and, therefore, since the movement of the plate is opposite to that of the piston, it will cover the ports in the slide valve sooner and so cause earlier cut off.

Since the slide valve and the expansion valve are moving in opposite directions during the first portion of the stroke of the piston, the cut off is very quick. The gear can be made to cut off very early without affecting the exhaust in any way.

Note that the point of cut off can be varied whilst the engine is running.

131. *Corliss and drop valves, and central exhaust*

1. **Purpose.**—Engines whose ratio of expansion is large in any one cylinder suffer from heavy condensation in the cylinders, unless means are employed to prevent it.

One of these means is to provide separate valves and ports for inlet and exhaust, so that high-pressure steam need not pass through passages that have just been cooled by exhaust steam.

2. **Drop valves.**—In drop-valve engines, steam is admitted by raising a *double-beat* valve, having two spherical seatings and arranged so that the steam pressure has only a slight effect in closing it, Pl. **112**, Fig. **7**. The valve, V, is raised by an arm, tripped at a point determined by the governor, and so released. Thus, if the engine speeds up, cut off is made to occur earlier and the mean effective pressure is reduced, with a corresponding economy in steam. The exhaust

valves may be larger than the inlet to allow the expanded steam to escape freely. They need no trip-gear and may be placed far from the inlet valves.

3. **Corliss valves.**—Corliss valves are arranged similarly to drop valves on the cylinder, and have also normally a trip-gear to the inlet valve, controlled by the governor, Pl. **112**, Fig. 6.

The valves are opened by revolving them in their cylindrical seatings, and so uncovering wide ports. They are closed by springs, controlled by dashpots to decrease noise and shock.

4. **Central exhaust engines** (Pl. **113**, Fig. 1).—In these, steam is admitted by either a drop valve or Corliss valve, while exhaust is effected by allowing the long piston to uncover a ring of ports in the centre of the cylinder. Thus steam flows through the cylinder in one direction, and owing to the temperature gradient which obtains down the cylinder, condensation is much reduced. Efficiency is thus better maintained with large expansion ratios.

The exhaust ports E, are very large and provide very free exhaust at the end of the stroke only. The return stroke compresses the unexhausted steam to a temperature and pressure approaching boiler steam conditions, thus further reducing initial condensation. The indicator diagram resembles that obtained with an air-blast Diesel engine. Central exhaust engines are also known as *Uniflow* engines. They are the most efficient slow-speed steam engines at present obtainable.

CHAPTER XXVII

CONDENSERS

132. *Object of condensers*

1. **The objects** of a condenser, applied to a reciprocating engine, are :—

   i. To reduce the back pressure upon the piston during its exhaust stroke, thus increasing the mean effective pressure.

   ii. To make it profitable to expand the steam to a lower pressure in the cylinder by early cut off, thus obtaining greater efficiency.

   iii. Incidentally its use enables the condensate to be returned for feed purposes.

2. These objects can be attained by producing a high vacuum in the condenser, placing it near the engine, and providing large exhaust valves and ports and a wide short exhaust pipe without unnecessary bends.

Since there is no internal pressure to be withstood, the exhaust pipe may be of cast-iron and of large diameter, but it should be provided with wide flanges and good jointing material to prevent air leaking in.

133. *Types of condensers*

1. **Surface condensers.**—Condensers are of several types, of which the most common is the surface condenser, normally consisting of a drum or chest, C, on Pl. **113**, Fig. 2, into which the steam is exhausted at E, and in which it is condensed by coming in contact with a number of metal tubes, T, cooled by circulating cold water, W, through them. A circulating pump is necessary, and in modern plant it is generally a centrifugal pump, direct coupled to an electric motor.

The condensate, or water produced by the condensation of the steam, is removed by a separate pump and delivered to the hot-well. It is not mixed at all with the cooling water.

The air which is present in the condenser before starting up, the air contained in the feed water, and any which may leak into the condenser while working, is removed by an air pump, A, or steam ejector. The condensate pump and air pump are often combined, since it is possible to design a pump which will deal with both simultaneously.

To assist in maintaining the temperature of the condensate, trays, R, should be fitted to catch the water dripping from

each bank of the condenser tubes as soon as it is condensed. Otherwise, if it is allowed to drip from tube to tube until it reaches the bottom, its temperature approximates more nearly to that of the cooling or circulating water, which is thus unnecessarily heated while the hot-well temperature is reduced.

2. **An open-air condenser,** Pl. **113,** Fig. 3, is used where the necessary quantity of cooling water is not available for an ordinary closed surface condenser.

It consists merely of a number of pipes placed in the open air, into which the exhaust steam is led to be condensed. The cooling action may be assisted by trickling water over the outside of the pipes. Since this cooling water is evaporated on the pipes, it absorbs approximately the latent heat of its own weight of steam. The amount of cooling water need never exceed the weight used by the engine, but it is all lost. It is difficult to keep the temperature low enough to maintain a good vacuum, and there are many joints which are difficult to keep air-tight. In desert countries and in mobile plants and vehicles, the recovery of water may be the principal reason for using a condenser, and this type of condenser is, therefore, suitable—of course, without the cooling water.

3. **Jet condensers.**—When space is of great importance, jet condensers may be used.

In these the steam is condensed by admixture with several times its weight of cooling water. The air and water may be removed by a pump, or, if sufficient head is available, by using the weight of the water either barometrically or by means of an ejector.

The *ejector condenser* consists of a series of nozzles or cones as shown on Pl. **113,** Fig. 4. Cold water at a head of about 20 feet is delivered into the nozzle, N, and passes right through the apparatus. Exhaust steam from E, entering the cones, C, is condensed, and, together with any air which may be mixed with it, is entrained and delivered through the infuser, J, by the enlargement of which the pressure of the mixture is brought to a little above atmospheric before it is discharged to the hot-well.

With all forms of jet condenser, only a small portion of the hot-well water can be used as crude feed water. The remainder should normally be cooled and used again in the jet.

134. *Condenser accessories*

1. **Condensing water coolers.**—The cooling water for use in any kind of condenser must be at a low temperature. Where a river or lake is available this can generally be managed

PLATE 113.

CENTRAL EXHAUST ENGINE. CONDENSERS & AIR PUMPS. FIXING A SEMI-PORTABLE ENGINE

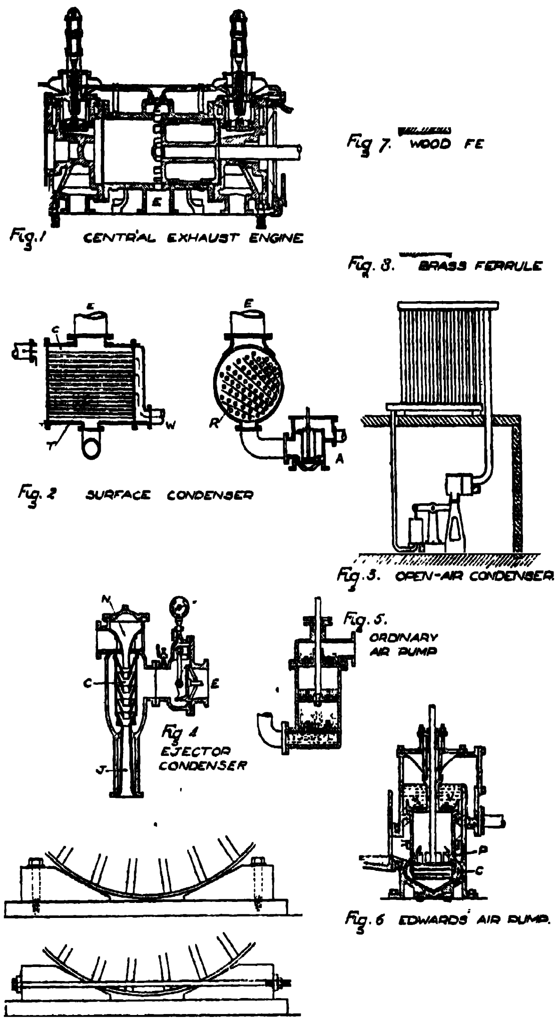


Fig. 1 CENTRAL EXHAUST ENGINE

Fig. 7. WOOD FE

Fig. 8. BRASS FERRULE

Fig. 2 SURFACE CONDENSER

Fig. 3. OPEN-AIR CONDENSER

Fig. 4 EJECTOR CONDENSER

Fig. 5. ORDINARY AIR PUMP

Fig. 6 EDWARDS' AIR PUMP.

Fig. 9. FIXING OF SEMI-PORTABLE ENGINE.

by drawing direct from the river or lake and returning the water to it after use. Otherwise, some device must be used to cool the water before using it again.

In small plants this can be effected by exposing the water in tanks to the air.

For larger plants some evaporative method is necessary. Either the water can be pumped to the top of a tower and allowed to trickle down over coke, broken brick, tiles, or some other porous material, or it can be sprayed into the air and caught in large flat reservoirs. A small portion is lost by evaporation and must be made up.

2. **Air pumps.**—The air in a condenser is usually removed by means of a pump working under water, which acts as a seal. The old type of air pump shown on Pl. **113**, Fig. 5, draws air, with any excess of water in the condenser base, into the cylinder, in which the water lies at the bottom. On the descending stroke the air, with any quantity of water above that which fills the clearance, passes above the piston through a non-return valve. On the up-stroke the air is expelled through the delivery valves, together with any water above that which will fill the clearance space above the piston.

In the Edwards' air pump (Pl. **113**, Fig. 6) the only valves are those in the top of the barrel. The condensed steam flows continuously by gravity from the condenser into the base of the pump. The air has a free passage from condenser to pump at all times.

On the down stroke the condensate passes round a curved passage C through ports P on the top of the piston. On the up stroke the condensate both air and water is entrapped above the piston and expelled through the delivery valves V.

The piston has no rings or leathers, but is turned an easy fit in the cylinder and contains several grooves which when water filled make it sufficiently air and water-tight. A relief valve is fitted to the base of the pump to prevent damage when starting up with the base full of water.

Steam air ejectors, combined with centrifugal extraction pumps, have now taken the place of the wet air pump, in all but very small plants.

3. **Leaks.**—Condenser tubes are very liable to develop leaks. In water-cooled surface condensers the effect is that cooling water enters the condenser and is removed to the storage tank with the condensate. If it becomes unnecessary to add make-up water, or if the level in the storage tank rises, this is a likely cause. The purifier should be made to deliver sufficient reagent to deal with this influx of crude water, as a temporary measure, and the condenser should be overhauled when an opportunity offers.

Wooden ferrules, Pl. 113, Fig. 7, are very liable to leak, especially after the condenser has been disused, even for a short period. New ferrules are the only remedy.

Brass ferrules, Pl. 113, Fig. 8, may be tightened if not seriously corroded.

Atmospheric condensers can only admit air, and so spoil the vacuum. The pipes should be examined for pinholes and for leaky joints. They are best found by filling the pipes with water and applying slight pressure by means of a hydraulic testing pump.

CHAPTER XXVIII

CARE AND RUNNING OF STEAM ENGINES

135. *Portable and semi-portable engines*

1. **Types.**—The semi-portable type of steam engine, Pl. **108**, Fig. 1, mounted upon a locomotive type boiler, is a type sometimes used in the service, and it is selected as a basis for the following sections, which apply to all simple medium-speed engines.

The type is suitable for active service use, since it is compact, mobile, and as economical as most engines of equal size.

There is normally one cylinder only. Two cylinders with cranks at 90° are sometimes supplied, and occasionally compound engines may be found, generally also with cranks at 90°. Each piston then has its own valve gear, and the machine may be regarded as two separate engines, except for the common bed and mainshaft bearing.

2. **Expansion of boiler.**—Since the boiler forms the bed or frame for the engine, it is important that the final adjustments to rods should be made while the boiler is under nearly full pressure.

Rough adjustments after overhaul can be made with the boiler cold, as explained in Sec. **41**. If the boiler is estimated to expand (say) $\frac{1}{8}$ in. the piston should be given $\frac{1}{4}$ in. more clearance at the crosshead end of the cylinder than at the other end, and the slide valve should be set to open the port on the crosshead side $\frac{1}{4}$ in. more than the port on the far side.

3. **Installation.**—A semi-portable engine, if kept on its wheels, needs no further foundation than a firm floor into which the wheels cannot sink, and wedges to prevent any movement or rocking when running. If no floor exists, a sleeper or baulk of timber laid lengthwise under each wheel will suffice, the wedges being nailed to the sleeper, Pl. **113**, Fig. 9, or drawn in by long bolts.

If the engine is to be used in a semi-permanent building, it may be taken off its wheels and the boiler lowered on to a brick or concrete bed. Only one end should be fixed, since the boiler must expand and contract.

4. **Starting.**—Before an engine is started, all lubricating devices should be filled and set working, the cylinder drain-cocks opened wide, and a little steam allowed to pass the

throttle to warm up the cylinder, the piston being on inner dead centre.

At first water will flow freely from the drain-cocks, and steam will issue when one cylinder end and the piston are warm.

The throttle should now be shut, the engine moved over to outer dead centre, and the other cylinder end warmed similarly by slightly opening the throttle. The engine may then be started by opening the throttle further and pulling the flywheel over to get off the dead centre.

The engine should be run slowly for a few minutes, with the drain-cocks slightly open, and then speeded up and the drain-cocks closed. At intervals the drain-cocks should be opened for a revolution, especially if any clicking sound should be heard in the cylinders.

5. **Running.**—Bearings should be felt occasionally, to ensure that if they begin to run hot it may be discovered before any seizing begins. This is particularly important in the case of a new engine, or one that has had any recent adjustments.

If a bearing commences to heat, the lubricating device should be examined at once, and, even if working properly, it should be set to supply more oil. Some thicker oil may be added with advantage. If the bearing continues to get hotter or if the engine shows any sign of labouring, the latter should be stopped and the former eased slightly and flooded with oil. When the bearing is cool, it may be tightened again and the engine restarted. If the bearing still persists in overheating, a test should be made for faulty alignment as described in Sec. **102.**

6. **Governor.**—The governors of semi-portable engines are generally driven by a belt, which is liable to slip off if it is slack or oily, or break if it is too tight. Apart from reasonable care in keeping the belt clean and at a proper tension, not too much reliance should at any time be placed upon the governor. The engine driver should always remain near the engine.

7. **Bearings.**—It is the duty of the driver to observe any knocks, however slight, that may develop, to discover in which bearings they appear, and to report the matter at once if increasing. As soon as an opportunity offers, the bearing should be taken up and properly bedded on the journal, as described in Sec. **37.**

8. **Stuffing glands.**—The piston and valve-rod glands must not be too tight, and in any case must never be tight enough to prevent one man turning the engine by the flywheel

rim. A very small steam leak is of no importance. If an excessive leakage occurs and cannot be stopped without tightening the gland to the point of making the engine difficult to turn, the packing should be removed and the rod examined to see whether it is grooved, bent, or out of line.

9. **Semi-portable engines.**—In the semi-portable type the engine and boiler are combined in one unit for compactness, and one man can be made responsible for the whole. The instructions given in Chapter XXII should be followed in every respect. More care is generally required by blowing down and washing out more frequently, since the water used may be very hard and no means may be available for softening it before use.

136. *High-speed engines*

1. **Types and uses.**—Steam engines running at high speed are used for :—

i. Locomotive vehicles.
ii. Generating electric power.

High-speed vertical engines of moderate size are generally compound, and of the type shown on Pl. **114.**

2. **Characteristics.**—High-speed engines are assembled with less clearance in the bearings to reduce wear ; the action is usually enclosed in a crankcase, C, Pl. **114,** and lubrication is nearly always supplied by pumping oil under pressure from a sump, S, to all bearings through ducts, D, in the crankshaft and through small pipes fixed to connecting-rods and valve-gear rods. The valves are normally of the piston-slide type, and sometimes one common valve supplies both cylinders.

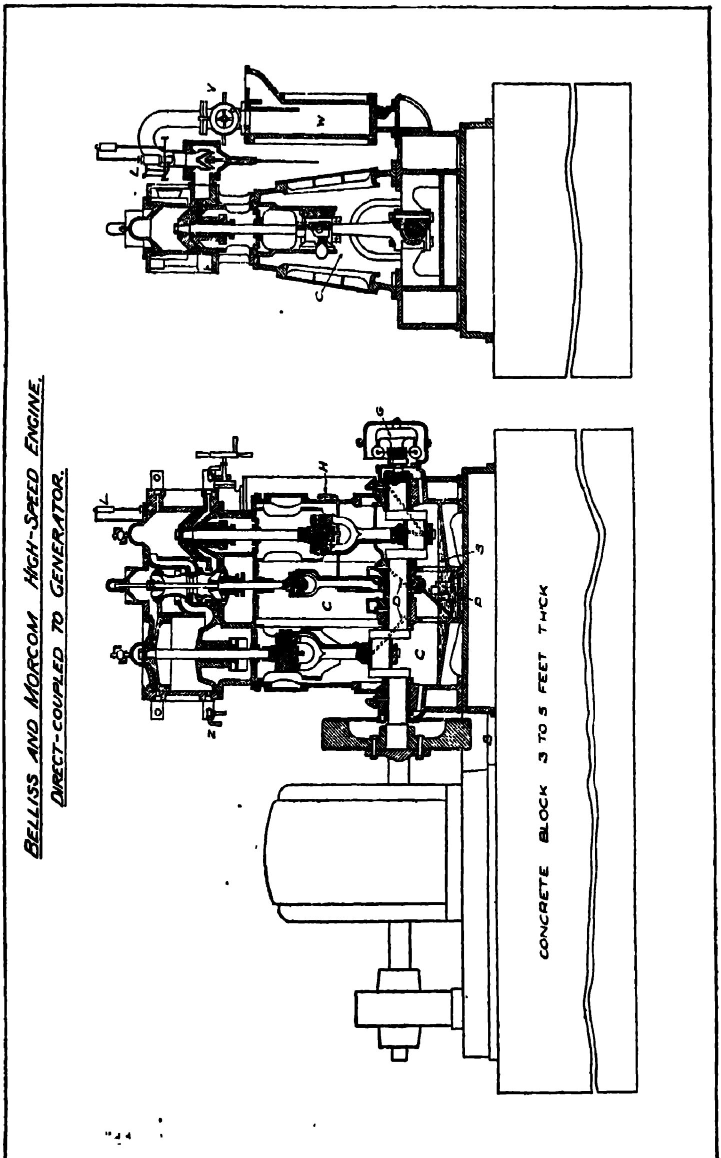
The governor, G, of the spring-controlled type, is generally mounted upon the crankshaft, and is sensitive and reliable.

3. **Lubrication.**—The engine sump, S, must be filled to the level specified by the makers with pure mineral oil of suitable quality (*see* Table **ZA,** page 604). The filter should be clean.

The oil need seldom be changed, but a little should be added weekly to ensure that the correct level is maintained ; any water which collects in the bottom of the sump should be drained off first. A pressure gauge, H, is fitted to show whether the pump, P, is working satisfactorily, and should indicate the pressure specified by the makers, which is usually from 10 to 20 lbs./sq. in. Much rise of pressure shows that the pipes are clogged.

4. **Installation.**—High-speed engines require good foundations, especially when directly coupled to electric generators.

PLATE 114.


BELLISS AND MORCOM HIGH-SPEED ENGINE.
DIRECT-COUPLED TO GENERATOR.
CONCRETE BLOCK 3 TO 5 FEET THICK

In permanent installations a concrete bed as specified by the makers, or at least three feet thick, should be provided, and also a cast-iron bed-plate, B, on Pl. **114**, to carry the engine and generator, with means for accurately lining up.

In semi-permanent and portable power plants, the engine and generator may be mounted upon steel joists not less than 10 inches deep. A flexible coupling between the engine and generator is advisable, unless the generator bearings are actually held in the bed-plate of the engine and the latter has been designed specially rigidly for use on such insecure foundations.

A water separator, W, should be fitted between the steam main and the engine steam-chest, provided with adequate drainage, such as a steam-trap of the falling-bucket type, Pl. **115**, Fig. 8.

5. **Starting.**—The valve lubricator, L, on Pl. **114**, should be set to deliver oil at the correct rate. The stop-valve, V, may then be opened very slightly and the drain-cocks, Z, opened to carry away all water that condenses.

A small engine should then be moved by hand for a few revolutions, or a large one should be cranked alternately to dead centres until the cylinders are warm. The engine should then be run at about 60 revolutions per minute until thoroughly warm, then gradually speeded up to its correct revolutions, the drain-cocks closed, and a load brought on gradually. The condenser stop-valve may then be opened and the atmospheric release valve closed.

The drain-cocks should be opened occasionally until the cylinders are thoroughly hot.

6. **Running.**—The engine should need little attention while running, provided the load is fairly constant. If it is possible to foresee sudden large increases of load, notice should be given to the engine-driver so that he may open the drain-cocks, since water is liable to collect in the cylinders when the governor first opens the throttle-valve wide.

7. **Stopping.**—Before stopping, the load should, if possible, be removed gradually, and the condenser stop-valve closed, so that the engine exhausts to atmosphere. Drain-cocks should be opened and the stop-valve gradually closed when the load is taken off entirely, but the engine should not be entirely deprived of steam until it has nearly come to a standstill.

The engine should be left with drain-cocks open so that the cylinders cannot fill with water.

For Bibliography, see page 689.

CHAPTER XXIX

LAY-OUT AND INSTALLATION OF STEAM PLANT

137. *Pipes and valves*

1. **Materials of pipes.**—The material suitable for use in steam pipes depends upon the pressure of the steam and the diameter of the pipe.

Cast-iron pipe with flanges cast integrally may be used for exhaust steam, or for heating purposes where the pressure is little above atmospheric.

All steam pipes of two inches diameter and less may be of welded strip similar to water barrel, but should be ordered to a steam specification. The joints may be screwed and packed with string and red lead.

High-pressure steam pipe of more than two inches diameter should be of solid drawn steel with flange joints, the flanges being screwed on and the pipe beaded out into a recess. Pl. **115**, Fig. 1.

The dimensions and specifications given in the British Standards Institution Specifications should be followed closely when making all fittings, and all material should be ordered from contractors on these specifications. Thus all pipes and fittings will match, and much difficulty will be avoided in erection.

2. **Jointing materials.**—Between the flanges some type of jointing is normally used. Various asbestos, rubber composition, and other fabricated jointings are on the market, and many are satisfactory for comparatively low pressures. For high pressures, and particularly for superheated steam, a metal packing is essential, placed in a shallow groove turned in the flanges.

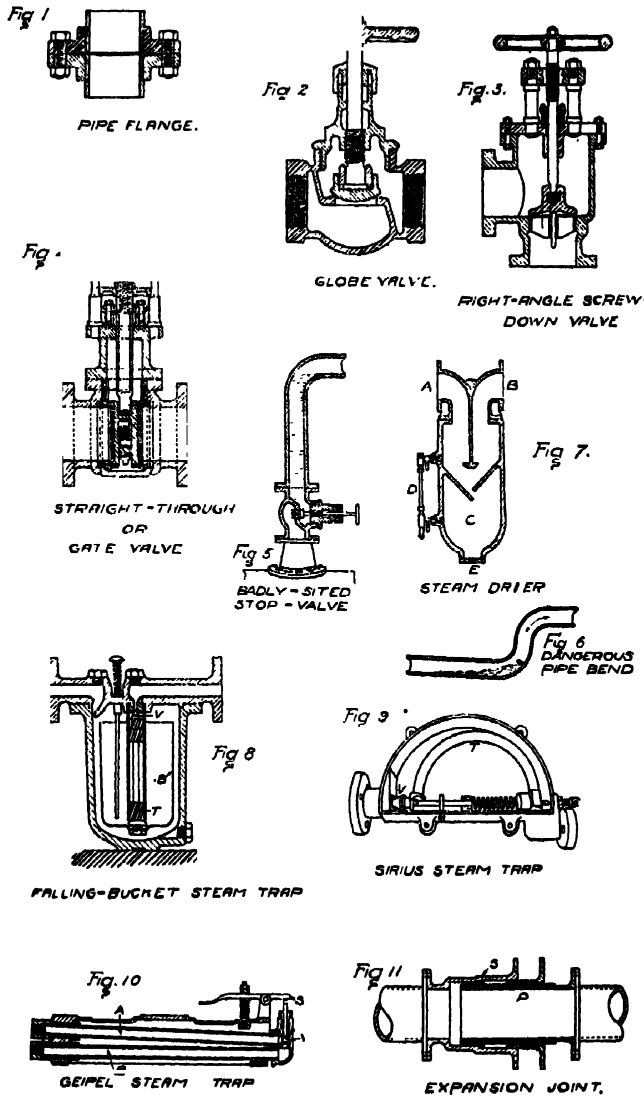
Corrugated washers of copper are suitable for saturated steam, and similar corrugated washers of steel may be obtained for use with superheated steam, which is liable to corrode flanges if copper is present.

3. **Size of pipe.**—Steam pipes should be large enough to carry the maximum quantity of steam ever likely to be required without exceeding a velocity of 5,000 feet per minute, *i.e.* the cross-sectional area in square feet should be not less than

$$\frac{\text{maximum cubic feet of steam per minute}}{5{,}000}.$$

Plate 115.

STEAM PIPES, VALVES, & FITTINGS.



4. Pressure drop.—The drop in pressure due to friction in steam piping can be calculated approximately from the Babcock formula :

$$W = 87{\cdot}5\,\frac{D(P_1 - P_2)d^5}{L(1 + \frac{3{\cdot}6}{d})}$$

where W = weight of steam flowing per minute in lbs.
D = weight per cubic foot (lbs.).
P_1 and P_2 = the initial and final pressure (lbs. per square inch).
d = diameter of pipe in inches.
L = length in feet.

This formula takes into account average frictional conditions.

The following table has been prepared from this formula for steam at various pressures, when the speed of flow is 5,000 feet per minute :—

Initial pressure, lbs. sq. in. (gauge)	Drop in pressure (lbs. sq in.) per 100 feet, straight length					
	Pipes					
	1-in.	$1\frac{1}{2}$-in.	2-in.	$2\frac{1}{2}$-in.	3-in.	4-in.
150	16·1	7·92	4·88	3·41	2·57	1·66
125	13·6	6·65	4·11	2·88	2·16	1·40
100	11·4	5·62	3·48	2·43	1·82	1·18
80	9·6	4·72	2·91	2·03	1·52	0·99
15	3·26	1·61	0·99	0·69	0·52	0·34
10	2·75	1·39	0·84	0·58	0·44	0·28
5	2·33	1·11	0·68	0·46	0·35	0·23

Sharp bends, elbows, valves of the globe type, and other obstructions greatly impede the flow. The drop in pressure at a globe valve may be taken as the same as for the following equivalent straight lengths of pipe :—

Pipe size—inches diameter	$\frac{3}{4}$	1	$1\frac{1}{2}$	2	$2\frac{1}{2}$	3	4
Equivalent length of straight pipe, feet	20	25	34	41	47	52	60

5. Valves.—Stop-valves should be cast with flanges integral, or screwed female in small sizes. Bodies are generally of bronze up to 2 inches in size, and of cast-iron or steel in larger sizes, with seatings and other wearing parts of renewable bronze or stainless steel. They should be so selected and sited in a pipe-line that water is unlikely to collect in them

when open, and that no large amount of water can collect in the pipe near them when closed.

The globe type, Pl. **115**, Fig. 2, is unsuitable for horizontal pipes, since water collects in the valve body.

The right-angle screw-down type, Pl. **115**, Fig. 3, is well suited for boiler stop-valves, if placed, as shown on Pl. **96**, Fig. 3, high above the boiler and the pipe is slightly sloped down away from the valve.

The straight-through, or gate, valve, Pl. **115**, Fig. 4, is the only type suitable for exhaust mains between an engine and condenser, since its resistance to the passage of steam is much less than that of globe or right-angle patterns.

138. *Pipe-lines*

1. **Pipe-lines.**—Pipes carrying steam, at whatever pressure, must be so sited that no water can collect in them anywhere. Otherwise, water hammer would be liable to occur, masses of water would be carried forward with the steam and thrown violently against bends or closed valves with an alarming noise, and produce stresses in the pipe that would cause joints to leak in minor cases, and might cause fracture and a dangerous explosion if the quantity of water were large.

On Pl. **115**, Fig. 5, the quantity of water collecting above the globe-valve might be sufficient to cause a disaster if the valve were suddenly opened. In such cases a steam trap must be fitted.

On Pl. **115**, Fig. 6, the water collecting in the bend will cause a distressing hammer and endanger the pipe-line farther on. Here again a steam trap is required.

If the pipe-line is so placed that the right-angle valve shown on Pl. **116**, Fig. 1, is at its highest point, with a slight but even gradient thenceforward to the engine, no large quantity of water can collect anywhere, because all condensate will travel forward with the steam as it precipitates.

2. **Steam driers.**—A steam drier or separator is merely a sufficiently large vessel in which the steam is made to turn a sharp corner, thus flinging out any liquid it contains into a sump, from which it can be drained. On Pl. **115**, Fig. 7, the steam entering downwards through A, turns sharply to emerge by B, and any liquid, whether water or oil, in suspension in the steam, tends to fly straight on into the sump, C, which is fitted with a gauge glass, D, so that the attendant can see how much is collecting. A drain, E, may be fitted with a valve which the attendant can open to let out water, or it should preferably be fitted with an automatic steam trap.

3. Steam traps.—Any dangerous point in a steam pipe-line and every steam drier should have a drain pipe led out at the bottom and descending to a steam trap. The latter is merely a device which permits water to escape, while confining the steam.

The *falling-bucket* type of trap, shown on Pl. **115**, Fig. 8, is bulky, but reliable in action. The bucket, B, normally floats and keeps the valve, V, closed to prevent the escape of steam. When sufficient water has collected, it will pour over the top and sink the bucket, the contents of which are ejected through the valve. Then the bucket floats again, and closes the valve until enough water has collected to repeat the cycle.

In this particular type, the valve is automatically ground-in by the spin of the bucket produced as the water flows through the turbine, T.

Many *temperature-operated traps* are available. They are comparatively cheap, but are apt to leak excessively unless the valve can be ground-in at intervals.

Pl. **115**, Fig. 9, shows a *Sirius* trap, which is much used for draining steam radiators, &c., on account of its low price. Liquid in the oval tube, T, expands if steam enters, and closes the valve, V. There is no easy means of grinding-in the valve, and the seatings are not renewable.

Pl. **115**, Fig. 10, shows a *Geipel* trap, whose valve, V, is closed by pressure against the stop, S, when steam enters the cantilever tubes, the lower one, B, being of brass, and the other one, A, of steel, so that a rise of temperature causes the cantilever to raise its apex. The valve is easily ground-in by gripping the squared portion of its shank with a key. The stop is adjustable and yielding, so that the apparatus cannot strain if excessively heated.

4. Expansion joints.—It is essential that steam pipes should be free to expand in length when steam enters, otherwise great strains will be caused in the pipes and joints, and walls or machinery may be damaged.

Large easy bends in the lay-out of the pipes will provide sufficient flexibility, provided the pipes are slung from brackets or girders and in no way rigidly fixed.

If a considerable length of pipe must be straight, a U-shaped piece should be introduced at least once every fifty feet to provide for expansion and contraction. The bend should be preferably in a horizontal plane to allow a free passage for water. If it stands vertically upward it will prevent water flowing and if hung downward it forms a water-pocket. In both cases careful drainage is necessitated. A special sliding joint is sometimes used, in which a portion of pipe, P, on Pl. **115**, Fig. 11, machined outside, is held in a stuffing box, S, in which it can move longitudinally.

5. **Lagging.**—All pipes carrying live steam should be lagged when possible, to prevent excessive loss of heat by radiation and convection.

Lagging materials must be soft and spongy, or their effect is small. The best materials, such as soft asbestos, slagwool, and magnesia, in coats about two inches thick, keep down the loss to about 250 B.Th.U. per square foot of external surface per hour or less, whereas bare steel, if dirty, loses about 1,000 B.Th.U. at ordinary steam temperatures.

A polished steel pipe only loses about 200 B.Th.U. per hour per square foot, copper or brass about 100, and plated pipes such as fitted to many modern engines, only about 50 if kept bright.

Soft lagging should be encased in varnished canvas, or in planished steel sheet to protect it and enhance its value. All lagging should be given a smooth finish to reduce its radiation. Aluminium paint is suitable for this.

6. **Identification.**—B.S.S. 3011—1929 lays down a system of colouring, by which pipes in a power station may be identified. The colours are very convenient and can be painted on the whole pipe or on bands nears the flanges. Stripes are longitudinal.

The principal colours are :—

Saturated steam	.. red.
Superheated steam	.. red with white stripe.
Exhaust steam	.. black with red flanges.
Cooling water (fresh)	.. sky blue with black stripe.
,, ,, (salt)	.. sea green.
Pure feedwater	.. sky blue with white stripe.
Compressed air	.. white with violet flanges.
Refrigerating pipes	.. French grey.

139. *Station lay-out*

1. **The engine-house.**—Pl. **116.** In siting the boiler, engine, condenser and auxiliary plant in any lay-out, whether large or small, the length of pipe should be kept to the minimum to save first cost, maintenance, and waste of heat from unnecessary surface.

The steam main, M, from boiler to engine should receive first consideration, since it loses heat very freely. The exhaust main, E, to the condenser may be considered next. Here heat loss is of no importance, but the pipe must be large, and is, therefore, expensive.

Pipes conveying water between auxiliaries are small, comparatively cheap, and lose little heat, but economy is worth considering.

PLATE 116.

BOILER ROOM AND ENGINE HOUSE.

FOR SMALL TEMPORARY POWER STATION IN THE FIELD.

SHOWING MINIMUM SPACES NECESSARY.

Fig 1.

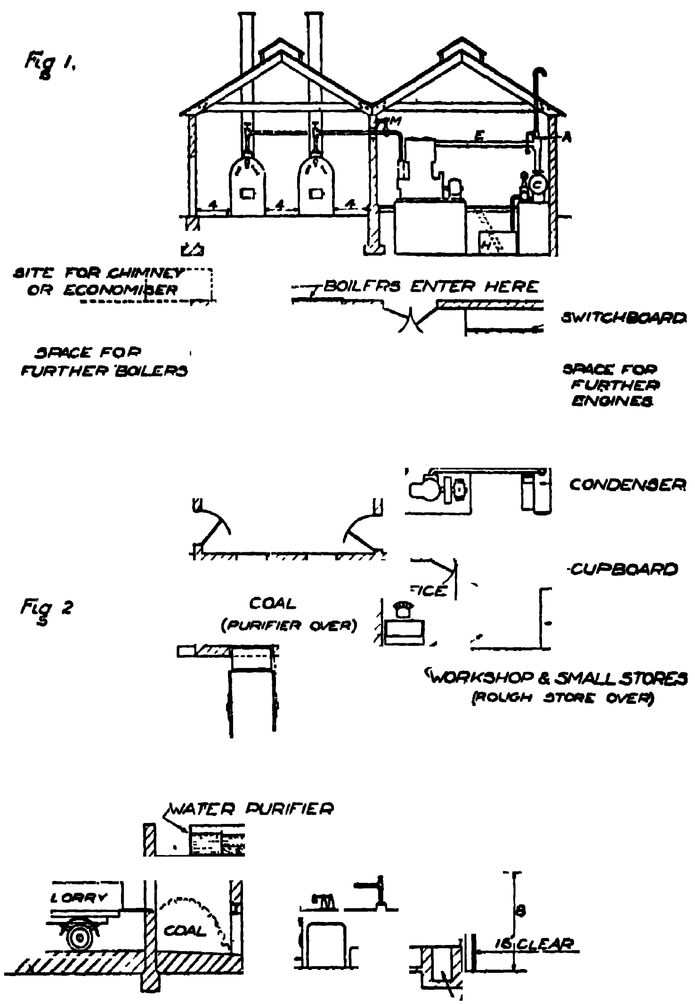


Fig 2

A hot-well, H, of ample capacity, should be provided, preferably in a pit below the condenser, C, but accessible for cleaning, into which the condensate from the main condenser and all steam traps should be led. Since feedwater heaters in the exhaust main line, and cocks and taps draining the low-pressure cylinders and exhaust main, will be under less than atmospheric pressure, their outlet pipes must be air-tight, and led to the condenser or to a closed vessel communicating therewith, sited to drain into it by gravity.

2. **The boiler-house.**—The boiler-house should be so sited, if possible, that coal may be brought to the bunkers by rail or lorry, and that the least effort is required to get coal from the bunkers into the furnace.

The floor of the bunkers should be about two feet above the boiler-house floor for hand firing, and about seven feet from the furnace door, *see* Pl. **116**, Fig. 3. Attendants can then reach the coal easily, and need not stoop to fill a shovel.

3. **Sample lay-out.**—

i. As an example, assume that a high-speed vertical engine taking 25 lb. of steam per B.H.P.-hour, according to the makers' specification, and coupled to a 35 kW. generator, is to be installed as a semi-permanent set, supplied with steam at 120-lb. gauge from two locomotive type boilers, and exhausting into a surface condenser.

The engine will be required to develop about 55 B.H.P. and may take 30 lb. of steam per B.H.P.-hour in adverse conditions. Therefore, 1,650 lb. of steam per hour should be allowed for, *i.e.* 27·5 lb. per minute, which, at 3·3 cubic feet per lb., equals 91 cubic feet per minute. The area of the steam main should be $91/5{,}000 = 0{\cdot}018$ square foot, or 2·6 square inches. A 2-in. main will suffice, and screwed tube may be used. It would be better practice to use rather larger piping with flange joints if the station were to be permanent, particularly because 2-in. pipe would not allow of the installation later on of another engine if the demand for power should increase.

The exhaust pipe should be similarly calculated for steam of, say, 3 lbs. pressure, and may be of cast-iron with gate valve and atmospheric release valve, A.

ii. Pl. **116** shows a general lay-out suitable for this plant.

The engine and its auxiliaries are placed in a separate room to keep them free from coal dust; they are grouped to keep all pipes as short as possible, and the hot-well consists of a steel tank in a pit below the condenser. In a permanent plant, standard practice would be to place the condenser also in a pit.

The ascending main from each boiler culminates in a screw-down right-angle isolation stop-valve to prevent live steam passing to a boiler under repair or during cleaning. Thence the steam main descends all the way to the steam drier at the engine. Either boiler main can be completely isolated by valves in the steam main in the engine room.

The boilers are grouped close to keep pipes short, but separated sufficiently to enable stays to be examined and replaced.

iii. Pl. **116**, Fig. 3, shows a section through the boiler-house. Space is left ahead of the boilers for sweeping out tubes and in front of the fire-boxes for the use of slices and rakes.

Coal is within reach, at knee level; it arrives by lorry without intermediate handling, and there is storage for a fortnight's supply.

The masonry block on which the smoke-boxes rest is hollow, and can be used as a flue when a separate chimney can be built. At first, steel chimneys can be used, ascending straight from the smoke-boxes, since nothing further is necessary unless an economizer is fitted.

iv. The wall farthest from the engine-room is unencumbered, so that the ground outside is available for adding further boilers or auxiliary plant, such as economizer and water purifier.

In a more permanent building the roof of the engine-room would be higher, and the walls would carry a travelling gantry for lifting machinery. Here, no such gear is supplied, and all machinery must be brought in on trucks and transferred to the beds on rollers; but this is bad practice and lifting gear should always be provided.

It is important to design doors so that machinery can be taken out. It is not advisable to place machinery and then build it in, since it may be necessary to move it at short notice. This applies equally to boilers.

CHAPTER XXX

ENGINE AND BOILER TESTING

140. *Introduction*

Engines and boilers should be tested—

i. On first installation to verify compliance with specification.
ii. After overhaul and repair.
iii. Periodically to check fuel consumption and general state of the plant.

The complete test of an engine would include :—

i. Verifying that the engine is capable of developing its rated B.H.P. at rated speed without overheating, noise, or vibration. This requires at least a 6 hours' continuous run—12 hours if to comply with British Standard Specifications.
ii. Measurement of fuel consumption per B.H.P.-hour at various loads.
iii. Measurement of lubricating oil consumption.
iv. Investigation of precisely what is occurring in the cylinder, so that faulty valves, ignition, &c., may be discovered and rectified.

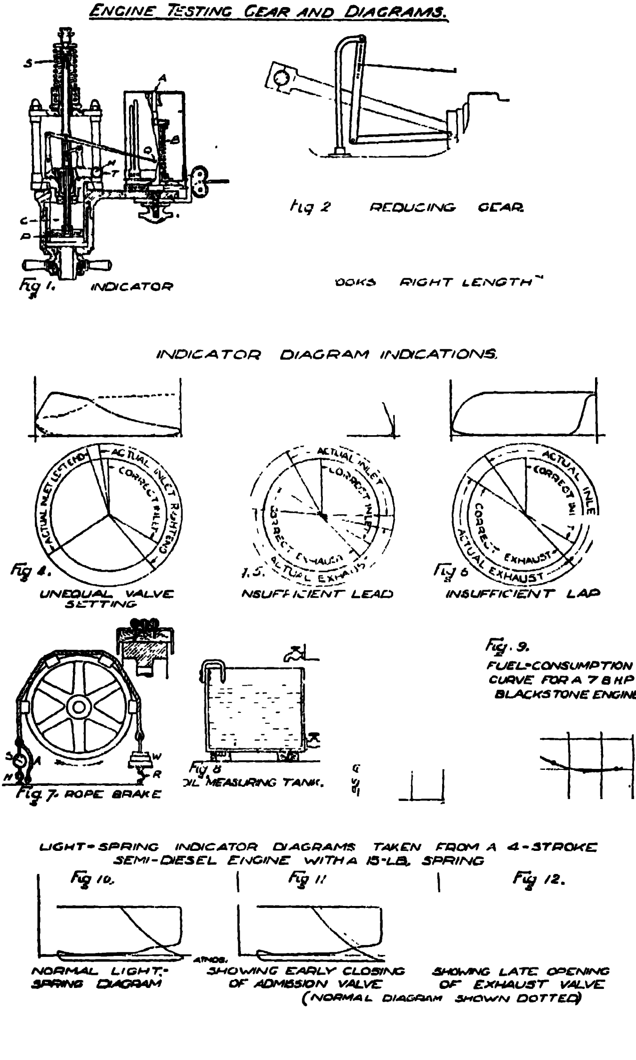
The indicator diagram is useful in this connection, but is inapplicable to high-speed engines (of the order 1,000 r.p.m.) except in a laboratory.

141. *Measurement of indicated horse-power*

1. **The indicator.**—An indicator consists primarily of a small cylinder, C, on Pl. **117**, Fig. 1, which can be placed in free communication with the engine cylinder. It contains a light, well fitting piston, P, free to move very easily under any change of pressure, and fitted with a spring, S, to regulate the movement of the piston according to the pressure. A pencil, Q, is carried by a system of light hinged levers so that it moves in a vertical line, proportionately to the movement of the piston, P, but magnifying its movements. A drum, D, to which a paper or indicator card can be fixed, is mounted on a vertical spindle, A, controlled by a spring, B, and is rotated by a string, G, wound round it, the other end of which can be attached to a point on the engine whose motion is the same as that of the piston of the engine.

When the stroke of the engine is inconveniently long a

PLATE 117.


ENGINE TESTING GEAR AND DIAGRAMS.
S
A
B
T
C
D
Fig 1. INDICATOR
Fig 2 REDUCING GEAR
OOKS RIGHT LENGTH
INDICATOR DIAGRAM INDICATIONS.
ACTUAL INLET LEFT END
ACTUAL INLET
CORRECT INLET
RIGHT END
Fig 4.
UNEQUAL VALVE SETTING
ACTUAL INLET
CORRECT INLET
CORRECT EXHAUST
ACTUAL EXHAUST
NSUFFICIENT LEAD
ACTUAL INLE
CORRECT INLET
CORRECT EXHAUST
ACTUAL EXHAUST
Fig 6
INSUFFICIENT LAP
Fig 7. ROPE BRAKE
W
R
A
H
Fig 8
OIL MEASURING TANK.
Fig. 9.
FUEL-CONSUMPTION CURVE FOR A 7 8 HP BLACKSTONE ENGINE
LIGHT-SPRING INDICATOR DIAGRAMS TAKEN FROM A 4-STROKE SEMI-DIESEL ENGINE WITH A 15-LB. SPRING
Fig 10.
Fig 11
Fig 12.
ATMOS.
NORMAL LIGHT-SPRING DIAGRAM
SHOWING EARLY CLOSING OF ADMISSION VALVE
SHOWING LATE OPENING OF EXHAUST VALVE
(NORMAL DIAGRAM SHOWN DOTTED)

reducing lever is used, as shown on Pl. **117**, Fig. 2, so that the movement of the piston is reproduced proportionately on a smaller scale.

The vertical movement of the pencil and the horizontal movement of the card combine to produce a closed figure, known as an *indicator diagram*, whose enclosed area measures the work developed during a stroke to a definite scale.

2. **Measurement of the indicated horse-power.**—The *mean effective pressure* (M.E.P.) during the cycle is the average height of the indicator diagram in units corresponding to the movement of the pencil for 1 lb. per square inch change of pressure. If the spring S on Pl. **117**, Fig. 1, is of such strength that 100 lb. per square inch increase of pressure raises the pencil 1 in. it is said to be a 100-lb. spring, and the height scale will be 1 in. = 100 lb./square inch. The M.E.P. is best found by measuring the area of the diagram with a *planimeter*, dividing by the length of the diagram and multiplying by the *spring number*. If a planimeter is not available the average height may be found by dividing the length of the diagram into a number of equal parts, as shown on Pl. **108**, Fig. 2, so that a number of strips of equal width are obtained. The heights of all the strips at their centre lines are measured and averaged. The M.E.P. so obtained is called the *indicated* M.E.P. (I.M.E.P.) to distinguish it from the *brake* M.E.P. (B.M.E.P.) dealt with later.

(Some writers call the I.M.E.P. the mean indicated pressure (M.I.P.), and the B.M.E.P. the brake mean pressure (B.M.P.).)

If P = I.M.E.P. in lb./square inch (in double-acting engines the mean of both diagrams).
L = length of stroke in feet.
A = area of piston in *square inches*.
N = number of *working* strokes per minute.

Then the indicated horse power (I.H.P.) $= \dfrac{\text{PLAN}}{33{,}000}$.

If n is the engine speed in revs. per min.

N = $2n$ for double-acting steam engines.
= n for single-acting steam engines.
= n for single-acting two-stroke I.C. engines.
= $\dfrac{n}{2}$ for single-acting four-stroke I.C. engines.

The common type of indicator illustrated in Pl. **117**, Fig. 1, is suitable for use on slow-speed engines only (say) up to 500 r.p.m. Special indicators are available for high-speed engines, but they are laboratory instruments, not in general use by the operating engineer. At best, no indicator

can be regarded as an instrument of great precision and, therefore, reliable measurements of I.H.P., are difficult to obtain.

Moreover, owing to friction losses and power taken to work auxiliaries, the actual power given out by an engine, viz.: the *brake horse-power* (B.H.P.), is always appreciably less than the I.H.P.

The ratio $\frac{\text{B.H.P.}}{\text{I.H.P.}}$ is evidently the *mechanical efficiency* of the engine, which varies from 75 per cent. to 90 per cent. at full load according to the size, type, and condition of the engine (*see* Table U, page 273).

The B.H.P. is what the user is chiefly concerned with, and this can be measured with simple apparatus fairly accurately. Working backwards, the B.M.E.P.

$$= \frac{33{,}000}{\text{L.A.N.}} \times \text{B.H.P.}$$

Note also that the *mechanical efficiency* $= \frac{\text{B.M.E.P.}}{\text{I.M.E.P.}}$

The distinction between I.M.E.P. and B.M.E.P. must be carefully borne in mind. As it is logical and customary to rate I.C. engines on their B.H.P., the use of I.M.E.P. is liable to be misleading.

3. **Care of indicators.**—

i. No indicator can be expected to give reliable diagrams unless it is in good condition and properly adjusted.

ii. The piston must be perfectly free to move in the cylinder; therefore both must be free from corrosion and dirt, and sufficiently lubricated.

iii. All pins must be free, but fit well enough to ensure no appreciable backlash. If any develops through wear, the holes should be reamered out and new pins fitted by an instrument maker or highly skilled turner.

iv. The arm carrying the pencil is limited in its swinging movement by a screw stop, T on Pl. **117**, Fig. 1. This must be set so that when the head is swung round by the handle, H, the pencil presses lightly upon the card, sufficiently to make a clear and continuous mark but not enough to tear the surface.

v. The pencil is generally of brass, and marks the aluminium surfaced card by burnishing it. The point should be gently filed occasionally to a good acorn-shaped point, fine enough to produce a

clear thin line, but with no tendency to dig into the surface and cut it.

vi. The string must be correctly adjusted for length, so that the drum does not touch either stop as the engine revolves. If the engine may be stopped, this can be done by placing the engine piston at inner dead centre, and adjusting the string so that the drum is well clear of its stop. As a check, the piston should be placed at outer dead centre, and the indicator string pulled out till the drum touches the outer stop, to ensure that there is a margin of play here. If the engine may not be stopped, the indicator string should be pulled right out till the drum touches its outer stop, and the hooks laid alongside but not hooked in, as shown on Pl. **117**, Fig. 3. The engine string should then be adjusted till it pulls nearly tight, but does not actually move the hook. The strings may then be safely hooked in. If they are too loose, this will be indicated by the drum striking its inner stop.

142. *Measurement of brake horse-power*

1. **The brake.**—Measurements of brake horse-power can be carried out with a rope brake, such as is shown on Pl. **117**, Fig. 7, stretched round the flywheel by a weight, W, and a spring balance, S, held by a hook, H. An extra hook with a loop, A, is also provided, so that it can be hooked in when readings are not actually being taken, and relieve the spring balance from unnecessary wear and the shocks of starting and stopping.

The friction between the rope and the flywheel keeps the weight, W, floating. The actual force against which the flywheel is working is $W - T$, where T is the tension registered by the spring balance.

To avoid accidents, the weights should be prevented from rising too much by anchoring them securely to a hook in the ground, by a string rope, R, which should, of course, be slack during the test. The weights should be attached to the brake by a string, weaker than the anchoring rope, and which will break before the latter if the brake should seize on the flywheel.

The simple brake here described can only be used for short periods owing to the heat developed. For continuous running a water brake must be used, or preferably a steady load such as an electric generator or a centrifugal pump.

2. **Power calculation.**—The work done in foot-lbs. per minute by the engine against the brake is $V(W - T)$, where V is the rim velocity of the brake wheel in feet per minute. The

B.H.P. is $\dfrac{2\pi RN(W-T)}{33{,}000}$, where the brake wheel of R feet radius revolves at N revolutions per minute.

143. *Testing steam plant*

1. **Scope of tests.**—In order to test any steam plant completely, it is necessary to ascertain :—

i. The efficiency of the boiler alone.
ii. The total efficiency of the boiler and its auxiliaries.
iii. The efficiency of the engine cylinders.
iv. The mechanical efficiency of the engine.
v. The total efficiency of the engine and condenser.
vi. The overall efficiency of the whole plant, from heat units in the fuel to B.H.P.

2. **Measurement of fuel.**—It is necessary for the test to last several hours to ensure accuracy in measuring coal fired into a boiler furnace. The test should not be commenced until the plant has been running for a few hours, so as to ensure that everything is normal. The coal may be accurately measured by balancing a barrow on the scales exactly, and then adding, say, 1 cwt. to the latter. The barrow may now be filled, wheeled on to the weighing machine, and quickly adjusted to hold precisely 1 cwt. by taking off or adding a little coal. To guard against mistakes, it is important to check each barrow load at a definite stage, *e.g.* before wheeling the barrow off the machine a set form of words should be enforced such as *weight correct*, answered by *load booked, move on*. The loads should be booked in some distinctive way such as 卌, representing a group of 5 cwts., the cross stroke completing the group and cancelling it. The coal should be fired into the furnace under supervision, and the conditions of the fire at starting and stopping the test should be the same. Any coal actually remaining unfired must be weighed and subtracted from the total booked.

3. **Calorific value of fuel.**—The calorific value of a sample of coal may be ascertained by any properly equipped physical laboratory. The test is based upon the principle that if a weighed sample of carefully selected and powdered coal is burnt under water, with sufficient oxygen supplied to ensure complete combustion, all the heat produced will be absorbed by the water, except for a small quantity escaping in the gases resulting from the combustion, and these can be made to bubble gradually through the water so as to carry little heat away.

i. In the *Thompson* or *bomb* form of calorimeter, the oxygen is supplied by mixing the powdered coal with some substance rich in oxygen, such as potassium

chlorate, thus forming an explosive mixture. This is ignited under water, in a metal container, made in diving-bell form to keep the mixture dry while allowing the gases to escape freely into the water. The water is weighed before being placed in the calorimeter, and its temperature is noted before and after the experiment. To the actual gain in heat units of the water must be added a correction, to allow for the heat absorbed or given out by the oxidizing agent in breaking up and that used to heat the bomb and containing vessel.

A mixture of 75 per cent. of potassium chlorate and 25 per cent. of potassium nitrate breaks up without any change in heat, the mixture constituting a balance in which as much is absorbed by the nitrate as the chlorate gives out.

ii. In the *Rosenhain* calorimeter the principle is the same, but the oxygen is supplied in gaseous form.

iii. Without making a combustion test, a fair idea of probable calorific value of a sample may be obtained by examination, especially if its place of origin is known ; further, very valuable indications are given by weighing the ashes left after burning a known quantity of coal, and by drying a weighed sample of coal to find the moisture content as supplied.

The calorific value of pure coal seldom varies much from 15,000 B.Th.U. per lb. ; therefore, a sample which contains 20 per cent. of ash and moisture cannot be expected to have more than 80 per cent. of this value, or 12,000 B.Th.U. per lb.

Any moisture in the coal lowers its calorific value, as it requires heat to evaporate it (*see* Sec. **61**).

4. **Measurement of water evaporated.**—The most accurate method of measuring the water evaporated by the boiler is to feed from a tank of known dimensions, filled to a mark, until the water level falls to another mark. The feed must then be shut off, the tank filled again to the higher mark, and the measurement booked.

The feed should be so arranged that the water level at the end of the test shall be exactly the same as it was at the start.

A water-meter may be used instead, but is seldom reliable.

5. **Measurement of load.**—The load on the engine, whether supplied by a brake or by some normal means such as making it supply power through an electrical generator, will vary to some extent. Readings should, therefore, be taken at least every half an hour or oftener, and the results averaged.

In the case of electric generating sets the k.W.h. meter should be read at the beginning and end of the run, and the total output so determined divided by the duration of the run in hours.

6. **Measurement of indicated horse-power.**—In view of the possible fluctuation of load and boiler pressure, indicator diagrams should be taken once or twice an hour, the I.H.P. being taken for each diagram, and the results averaged.

7. **Temperature and general records.**—The boiler pressure, temperature of feedwater entering the boiler, and in the case of a condensing plant, vacuum, temperatures of hot-well, cooling water entering and leaving the condenser, quantity of cooling water used, and, if possible, temperature of flue gases, should be recorded every half an hour. Where a feedwater heater and economizer are fitted, the temperature of the water entering the feedwater heater and passing to the economizer should also be recorded. *See* Form 1.

8. **Calculation of efficiencies and losses.**—A guide to the calculation of results is given in Form 2, for a plant in an electrical power station. Typical efficiencies to be expected can be deduced from Tables **X** and **Y**.

9. **Information given by shape of indicator diagrams.**—Indicator diagrams must not be expected to conform exactly to the theoretical shape shown on Pl. **109**, Fig. 1. The gradual closing of valves, and the inertia effects in the gas or steam and also in the moving parts of the indicator, round off corners and cause undulations in the lines of such magnitude that the expansion curve may be completely disguised.

Serious errors in valve setting will, however, show certain definite signs :—

i. Errors may be due, in the case of a slide valve, to inaccurate adjustment of the length of valve rod, causing a larger and longer opening of one port and a considerable difference between the diagrams from the two cylinder ends, as shown on Pl. **117**, Fig. 4.

ii. Inaccuracy in setting the eccentric will affect both cylinder ends equally. Pl. **117**, Fig. 5, is a typical diagram from an engine whose eccentric has slipped back. There is no cushioning at the end of the exhaust stroke, admission is late, cut off does not occur till somewhat late in the stroke, and exhaust only commences at the outer dead centre.

iii. Pl. **117**, Fig. 6, is typical of excessive lead as regards the inlet, which is very early, but the cut off is late and the exhaust about correct. This cannot be due

to an error in the eccentric, but is due to the slide valve having insufficient lap. This effect may be due to rounding off the edges of the valve and ports, which allow steam to enter too soon and continue to enter after the theoretical point of cut off.

144. *Testing internal-combustion engines*

1. Sections **140, 141** and **142** apply equally well here, but to supplement the indicator diagram a good deal can be judged from the colour, noise and temperature of the exhaust.

In multi-cylinder engines, if all the cylinders are sharing the load equally the exhaust temperatures should be equal. The exhaust temperatures vary with the load, somewhat as follows, in solid-injection heavy-oil engines :—

10 per cent. overload	775° F.
Full load	675° F.
¾ load	550° F.
½ ,, ...	400° F.
¼ ,, ...	300° F.
No load	230° F.

2. **Valve setting.**—Faults in valve setting are best shown by light-spring diagrams, *i.e.* taken with an indicator fitted with a spring which allows the pencil to move 1 in. for, say, 20 lb. difference in pressure.

Pl. **117,** Fig. 10, shows a normal diagram, and Figs. 11 and 12, show typical faults.

3. **Typical indicator diagrams.**—Pl. **79** shows typical indicator diagrams obtained with Diesel engines in good condition at various loads.

4. **Typical performance curves.**—Pl. **118** gives typical performance curves and a heat balance for a 250-B.H.P. solid-injection heavy-oil engine.

Also Pl. **117,** Fig. 9, shows the fuel consumption curve for a 7-B.H.P. slow-speed horizontal oil (paraffin) engine.

5. **Tabulation of results.**—Typical *pro forma* for tabulating results are given in Forms 3, 4, and 5.

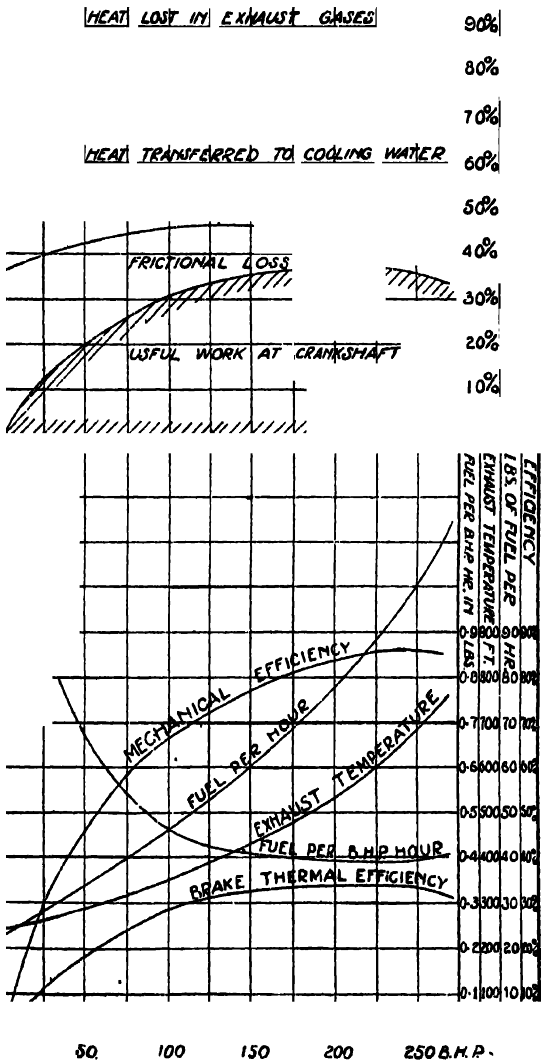
6. **Measuring the fuel.**—The fuel is contained in tanks which may be :—

i. Above the engine.
ii. In the bed of the engine.
iii. Separate.

i. *Tank above the engine.*—Run the engine under full load on the brake at its rated speed until the cooling water has attained its usual working temperature (140° F.) on top of the cylinder. Fill the fuel tank completely, or up to some mark

PLATE 118.

HEAT BALANCE AND PERFORMANCE CURVES
250 B.H.P. SOLID INJECTION HEAVY OIL ENGINE.



BRAKE HORSE POWER

therein, and run the engine for some definite time (say, 1 hour) with constant load. Then refill the tank, *weighing* the quantity of fuel required to do so.

ii. *Tank in the engine bed.*—Obtain a separate tank of suitable dimensions, Pl. **117**, Fig. 8, fitted with a pointer which can be adjusted vertically. When ready to commence the test, adjust the pointer until its point is just below the surface. Note the time when the fuel drops off the point. Add a measured quantity of fuel which will keep the engine running for about 1 hour. Note the time when the fuel again drops off the pointer.

iii. *Separate tank.*—Employ the pointer method as in (ii). The pointer method is very accurate. It cannot be used where engine tanks are fixed to the engine, owing to vibration, nor where tank-filler caps are small.

TABLE X.—*Sample performances of steam engines on makers' tests at various loads*

(Add 25 per cent. for normal working)

Type of engine	Condensing or not	Rated B.H.P.	Valve gear	Boiler Pressure	Superheat	Consumption of steam in lbs. per B.H.P. hour: Full load	Half load	$\frac{1}{3}$ load	$\frac{1}{4}$ load	25% over-load	50% over-load
Simple portable	No	10	Slide	60	No	65	77	84	110	70	Slows
Compound portable	"	30	"	120	"	40	46	52	64	45	"
Simple stationary	"	100	"	100	"	33	38	44	48	36	"
" "	"	100	"	100	Yes	16	19	21	24	17	"
" "	Yes	100	"	100	No	24	29	34	38	27	"
" "	"	100	"	100	Yes	13	15	18	21	15	"
Compound stationary ..	No	200	Meyer	130	No	18	21	24	26	20	22
" "	Yes	100	{Drop or Corliss}	120	"	14	16	19	22	15	17
Central-exhaust stationary ..	"	600	Uniflow	160	Yes	12	14	16	20	13	15
High-speed compound ..	"	100	Piston (slide)	130	No	20	22	24	30	21	Slows
" " " ..	"	250	"	150	"	19	19	22	23	20	"
Turbine	"	700	—	160	Yes	12·5	14	15	17	12·5	13
"	"	7,000	—	160	"	10	12	13	15	10	11
"	"	25,000	—	250	250° F.	7·6	7·8	8	8·4	7·8	—

Table Y.—*Sample performances of steam boilers on test, when new, with various fuels*

normal working from 10 to 20 per cent. less output must be expected. For installation, allow 25 per cen less than these figures

of bo:	Fu	Calorif value	Method firing	Draugh	Fuel consumption in lbs. per square foot of grate area, per hour	Water evaporation in lbs. per square foot of heating area, per hour, F. & A. 212	Water evaporated, &c. in lbs. per square foot of heat area when an economizer is fitted	Efficiency without economizer	Efficiency with economizer	Lbs. of water evaporated per lb. of fuel without economizer	Lbs. of water evaporated per lb. of fuel with economizer	Boiler pressure. Lbs. per square inch gauge
Vertical shell—												
Galloway tubes ..	Coal	1,000	.nd	Sligh	12	6		45		5		00
Cornish	,,	1,000		$\frac{3}{8}$ in	25	6		45	60	5	7	00
Lancashire	,,	1,000	,,	$\frac{3}{4}$ in.	30	o 7		50	60	6	7	30
,, ...	,,	1,000	.utomati	$\frac{3}{4}$ in.	45	7		60	75	7	9	30
,, ...	Oil	8,500	Pressure-oil	$\frac{3}{4}$ in.	—	9		62	73	2	4	30
Locomotive, semi-portable	Coal	1,000	Hand	$\frac{3}{8}$ in.	20	5		60	65	7	8	20
,, railway ..	,,	2,000	,,	5 in.	50	·2		78		0		80
,, ,, ..	Oil	8,500	:eam injectio	2 in.		:5		78		5		80
Economic, Lancashire, with fire tubes	Coal	1,000	Han	$\frac{3}{4}$ in	30	6	7	60	75		9	130
Economic	Oil	8,500	—	$\frac{3}{4}$ in	—	—	—	68	78		5	130
Water-tube	Coal	1,000	Hand	$\frac{3}{8}$ in	20	5	6	60	75		9	130
	,,	2,000	.utomati	$\frac{3}{4}$ in	25	6·	7	60	75		9·5	200
	Oil	8,500	Pressure-oil	$\frac{3}{4}$ in		7	20	73	85		6	250

Form 1.—BOOKINGS OF TEST OF STEAM PLANT AT .... ON ....

Coal used, lbs.																		
Water used, gallons																		
Wattmeter reading, main switchboard																		
Watthour meter, main switchboard																		
Watthour meter, recording power taken by auxiliaries ..																		
Boiler pressure																		
Temperature of feed-water into boiler																		
Temperature of water entering economizer																		
Temperature of cooling water into condenser																		
Temperature of cooling water from condenser																		
Temperature in hot well																		
Temperature of flue gases leaving boiler																		
Temperature of flue gases leaving economizer																		
Vacuum, inches of mercury																		
Barometer, inches of mercury																		
Draught, inches of water																		
Percentage CO_2 in flue gases																		
Percentage CO in flue gases																		
From Indicator Diagrams: M.E.P. H.P. cylinder																		
From Indicator Diagrams: M.E.P. L.P. cylinder																		
From Indicator Diagrams: I.H.P. H.P. cylinder																		
From Indicator Diagrams: I.H.P. L.P. cylinder																		
From Indicator Diagrams: Total I.H.P.																		

Form 2.—ANALYSIS OF RESULTS OF TEST ON STEAM PLANT

1	Total weight of coal burnt	lb.	from bookings.
2	Calorific value of coal per lb.	B.Th.U.	
3	*Total heat units in coal used*	B.Th.U.	(1) × (2).
4	Total weight of water used	lb.	Gallons × 10.
5	Total heat of 1 lb. steam at average boiler pressure ..	B.Th.U.	Steam tables.
6	Average temperature of water entering boiler	deg. F.	from bookings.
7	*Total heat units given by boiler*	B.Th.U.	(4) × [(5) + 32° − (6)].
8	Evaporation of water per hour from ° to °	lb.	(4) ÷ *x* (hours duration of test).
9	„ „ „ from and at 212° F. ..	lb.	(7) ÷ 966 *x*.
10	Evaporation per lb. of coal from ° to °	lb.	(4) ÷ (1).
11	„ „ „ from and at 212° F.	lb.	(10 × (9) ÷ (8).
12	Coal burnt per hour per square foot of grate area ..	lb.	(1) ÷ (*x* × grate area).
13	*Efficiency of boiler alone*	%	(7) ÷ (3) × 100.
14	Temp. rise of feed water in passing through economizer ..	deg. F.	from bookings.
15	Total heat recovered by economizer	B.Th.U.	(4) × (14).
16	„ units in steam used	B.Th.U.	(7) + (15).
17	Average vacuum maintained	ins.	from bookings.
18	„ rise of temperature of condenser water	deg. F.	from bookings.
19	Total water circulated through condenser	lb.	Pump delivery in G.P.H. × 60 × 10 × *x*.
20	*Heat units lost in condenser*	B.Th.U.	(18 × (19).
21	Average I.H.P. of engine	H.P.	from bookings.
22	Total I.H.P. hours	—	(21) × *x*.
23	*Heat units equivalent of I.H.P. hours*	B.Th.U.	(21) × *x* × 60 × 33,000 ÷ 778.
24	Steam consumption per I.H.P. hour	lb.	(4) ÷ (22).
25	*Thermal efficiency of engine*	%	(23) ÷ (16) × 100.
26	Total electrical energy generated	k.W.h.	from bookings.
27	Average electrical power output	k.W.	(26) ÷ *x*.
28	„ B.H.P.	H.P.	(27) ÷ 746 × 100 ÷ 87.
29	*Mechanical efficiency of engine*	%	(28) ÷ (21) × 100.
30	Electrical energy taken by auxiliaries	k.W.h.	from bookings.
31	Nett electrical output to busbars	k.W.h.	(26) − (30).
32	„ mechanical output of engine	B.H.P. hrs.	(31) ÷ 746 × 100 ÷ 87.
33	*Steam consumption per nett B.H.P. hour*	lb.	(4) ÷ (32).
34	„ „ „ k.W.h.	lb.	(4) ÷ (31).
35	Fuel consumption per nett B.H.P. hour	lb.	(1) ÷ (32).
36	„ „ „ k.W.h.	lb.	(1) ÷ (31).
37	*Overall efficiency, fuel to electrical output*	%	31) × 3,410 ÷ (3) × 100.
38	Radiation, flue gas and other losses..	B.Th.U.	(7) + (15) − (20) − (23).
39			
40			

Form 3.—TEST OF I.C. ENGINE

Engine.																			Generator.						
			Temperatures °F.									I.H.P.				B.H.P.			Temperatures.			Output.			
				Cooling water.		Cylinder jackets.			Exhaust.			Cylinders.													
Load.	Time.	Period hours.	Air.	Inlet.	Outlet.	1	2	3	1	2	3	1	2	3	Total.	Equivalent kilowatts.	H.P.	Mechanical efficiency.	Alternator stator °C.	Exciter field °C.	Speed r.p.m.	Reading of k.W.h. meter.	k.W.	Generator efficiency.	Generator input.
Full load.		0																							
		¼																							
		½																							
		¾																							
		1																							
		1¼																							
		1½																							
		1¾																							
		2																							
		2¼																							
		2½																							
		2¾																							
		3																							
Half load.		½																							
Quarter load.		½																							
No load.		½																							

Form 4.—TEST OF I.C. ENGINE

The following values are required for full load, half load, and quarter load:—

	Full load.	Half load.	Quarter load.
(1) Total fuel consumed during period .. lbs.			
(2) Equivalent British Thermal Units			
(3) Total B.H.P. hrs. during period			
(4) Equivalent British Thermal Units			
(5) Total k.W.h. generated during period ..			
(6) Equivalent British Thermal Units			
(7) Average fuel consumption per k.W.h. ..			
(8) Average fuel consumed per B.H.P. hr. ..			
Brake Thermal efficiency of engine .. .. = (4) ÷ (2)			
Overall energy efficiency of generating set .. = (6) ÷ (2)			

Useful Constants.

1 k.W.h. = 3,410 B.Th.U.
1 H.P. hr. = 2,545 „

Form 5.—HEAT LOST TO COOLING WATER

Time.	Period.	Temperature.		Rise of temp.	Rate of flow.	B.Th.U.
		Inlet.	Outlet.			
	0					
	$\frac{1}{4}$					
	$\frac{1}{2}$					
	$\frac{3}{4}$					
	1					
	$1\frac{1}{4}$					
	$1\frac{1}{2}$					
	$1\frac{3}{4}$					
	2					
	$2\frac{1}{4}$					
	$2\frac{1}{2}$					
	$2\frac{3}{4}$					
	3					

Total B.Th.U. to cooling water

Total B.Th.U. of fuel consumed

% of heat units lost to cooling water..

CHAPTER XXXI

SELECTION AND ERECTION OF ENGINES

145. *Selection of prime movers*

1. The choice is in most cases limited to two or three possible types by the following main factors :—

i. Portability.
ii. Power required.
iii. Reliability.
iv. Simplicity.
v. Overload capacity.
vi. Fuel available.
vii. Starting torque.
viii. Suitable speed.
ix. Space available.
x. Cyclic regularity.
xi. Absence of vibration.
xii. Silence.
xiii. Economy in fuel, &c.
xiv. Economy in first cost.
xv. Economy under variable load.

2. For military purposes portability is often the most important consideration. It must be remembered, however, that reliability generally decreases as portability increases.

Speeds are of little consequence if belt drive is used, but become important where direct-coupling can be applied.

Starting torque can be dispensed with in many cases by fitting a clutch or shifting belt.

Space, silence, cyclic regularity, vibration, and economy are seldom very important factors in temporary installations.

3. Steam plant is generally bulky and requires a larger staff to run it than oil or petrol engines; on the other hand, it is extremely reliable and hard wearing, and in the simpler types requires comparatively unskilled attention. The portable type, mounted, with locomotive type boiler, on wheels, is a convenient engine where rapid installation is necessary.

The heavy starting torque and high overload capacity of a steam engine are useful where demands for power are heavy but intermittent.

In wood-working of all kinds the refuse can be used as fuel, and in this case a wood-fired boiler and steam engine may be suitable.

4. Petrol engines should be avoided for continuous work

unless extreme lightness is of first importance. They are useful for portable engines for intermittent work.

The high-speed solid-injection Diesel engine, however, is almost as light, is more efficient, burns a cheaper fuel and appears to be quite as simple and reliable as the petrol engine.

For further information *see* Chap. XIV.

5. The foregoing remarks, together with Table **Z**, will afford some guidance in the problem of selecting a prime mover for any ordinary purpose in the field.

Demands for engines should specify as fully as possible the purposes for which they are required, maximum continuous working load anticipated, limitations of speed, nature of fuel available, water-supply facilities, diameter and width of driving pulley (if required), and particulars of any special accessories required.

6. **Other types.**—Although some types are shown in Table **Z** as unsuitable or undesirable for certain reasons, it is desirable that military personnel shall have sufficient knowledge to run such plant, which may have to be taken over in the field from civil or enemy sources.

146. *Engine foundations*

1. All engines, when at work, have unbalanced forces which tend to give them either vertical or horizontal movement. This is especially so in the case of single-cylinder engines.

Foundations are required in order to restrain this movement, and the size of the foundation has to be determined by the manufacturers of the engines from their knowledge of the unbalanced forces and, to a certain extent, by experience. Consequently, the maker's foundation plans should be carefully worked to if they are available.

2. The fact that the unbalanced forces within the horizontal engine are usually greater in the horizontal direction makes it obvious that great care has to be taken to get a good solid foundation block, but although the vertical engine produces less strain on the foundations, it is equally important to have the same solidity and homogeneity.

3. An insufficient foundation is usually a continual source of trouble, which, if not remedied, eventually results in costly repairs to the engine. Also, in addition to the risk of unequal settlement and fracture of the foundation block, there is always the danger of excessive vibration being set up in the surrounding soil, which may cause damage or annoyance, and which constitutes a public nuisance.

ines

r work in the fi

Cost per B.H.P.		
To instal	To run	
V.S. V.S. M. V.S. S. S. S.	H. H. H. H. H. H. H.	
L. S.	S. H.	
L. M. L. L. L. M. L. L.	V.S. V.S. V.S. V.S. V.S. V.S. V.S. V.S.	
V.L. V.L. L. V.L. V.L.	F. F. L. S. V.S.	
L. L.	L. S.	

= large, M. = m

these speeds.

4. **Choice of material.**—A concrete block is best for foundations and is preferable to ordinary building bricks. The best quality concrete should be used, the proportions being 1 : 2 : 4.

5. **Dimensions.**—Before deciding on the dimensions of the foundations, the nature of the soil should always be considered. A hard gravel bottom is the usual standard for comparison ; for soft soils the weight that can be carried on an equal surface is much less, so the area of the foundation must be greater and, if the ground is very soft, it may be necessary to use piles or a reinforced raft to carry the weight.

6. The depth of foundation given by the engine-maker should not be reduced if it can be avoided, and in such cases the foundation must be strengthened by placing old girders or steel rails lengthwise in the mass of concrete ; this or some other method of strengthening is essential if there is a race for the engine flywheel cutting into the foundation.

7. If buildings are situated near by and it is essential to avoid vibration, the character of the subsoil should be investigated before making the foundation, and if this trouble is feared, the advice of the engine-makers should be obtained.

8. If the engine-maker's foundation plans are not available, the following tables can be taken as a guide for good soil :—

Foundations for horizontal oil engines (single-cylinder)

B.H.P.	Foundation.		Holding-down bolts.	
	Base area (square feet).	Minimum depth.	No.	Diameter.
Up to 16	Up to 40	2 ft.	4	$\frac{7}{8}$ in.
20 to 50	50 to 60	2 ft. 6 in. to 4 ft.	4	1 in. to 1$\frac{1}{8}$ in.
51 to 100	70 to 160	4 ft. 6 in. to 5 ft.	6	1$\frac{1}{4}$ in. to 1$\frac{1}{2}$ in.
101 to 150	160 to 200	5 ft. to 6 ft. 6 in.	6	1$\frac{1}{2}$ in. to 1$\frac{3}{4}$ in.

Foundations for vertical Diesel single-cylinder engines

B.H.P.	Foundation.	
	Base area (square feet).	Depth.
30	22	4 ft.
65	68	5 ft.

In the case of high-speed self-contained sets mounted on rolled steel joists, a hard floor is a sufficient foundation.

9. For horizontal engines up to 30 B.H.P., if the block is made about one foot wider and two feet longer than the engine bed, it will usually be large enough; but for larger engines provided with a pedestal bearing for the support of the crankshaft beyond the flywheel and pulley, it is essential that the block shall be large enough to support this pedestal as well as the engine itself.

Pl. **119**, Fig. 1, shows an example of foundation lay-out for an 85 B.H.P. oil engine. The height of the block above the engine-room floor is a matter of convenience in operating the engine.

10. **Method of construction.**—The necessary excavation having been made, the position of the holding-down bolts is located by means of square wooden boxes, large enough to enable the holding-down bolts and plates to be put into position after the concrete has set and the boxes removed, Pl. **119**, Fig. 2.

The boxes should be attached to a template to prevent any movement whilst ramming in the concrete. Depth of bolt holes should be sufficient to allow bolt to drop in to clear the top of the bed. Thin wires are attached to the threaded portions of the bolts and then passed through the holes in the engine bed. The bolts may then be pulled through when bed is in position. All bolts must hang vertically.

For engines and other machines not liable to severe vibrations in a vertical direction, it is satisfactory to use boxes with parallel sides. Provided the concrete is cleaned and roughened after removing the boxes, the parallel sided plug of cement formed by grouting in the bolts will hold firmly.

As an additional safeguard in the case of machines subject to severe vertical vibration, the boxes may be tapered, the larger end being downwards. The construction of the tapered boxes is shown in Pl. **119**, Fig. 2. Provided the width at the bottom is not greater than the diagonal of the top opening, with due allowance for the thickness of the boards, the sides can be knocked inwards, twisted to the diagonal position, and withdrawn. The proportions shown provide the necessary clearance.

The boxes should be greased or soaped on the outside to prevent them from sticking to the concrete. They should rest on a block of wood (which can be left in the foundation) to prevent the concrete rising up in the box.

The concrete can now be put in and well rammed in the usual way. When the foundation is completed, several days or weeks should elapse before placing any heavy weight on it, so that it may be set uniformly. The bolt boxes, however, should be removed immediately the concrete has set sufficiently to stand.

PLATE 119.

ENGINE AND MACHINE FOUNDATIONS

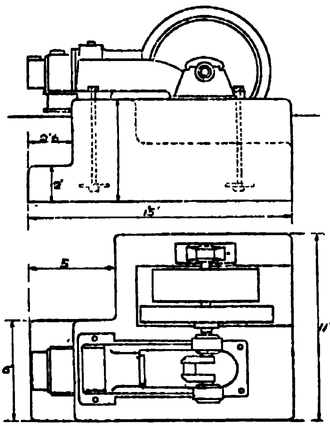


Fig 1 FOUNDATION LAYOUT OF 85 BHP OIL ENGINE

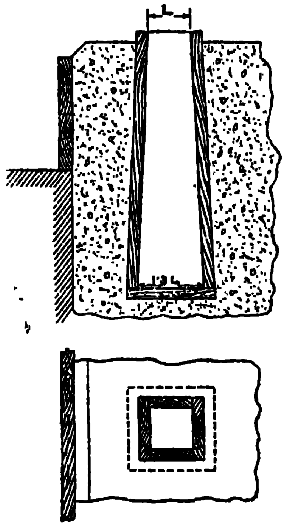


Fig. 2 FOUNDATION BLOCK SHOWING BOLT-HOLES & BOXES

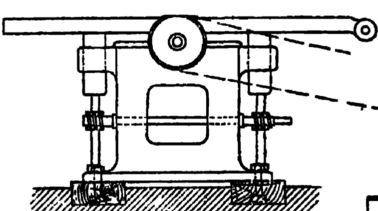


Fig 3 TIMBER FOOTINGS FOR CIRCULAR - SAW BENCH

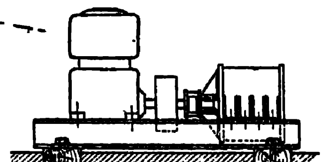


Fig 4 FOUNDATION FRAME FOR DIRECT-COUPLED TURBINE SET

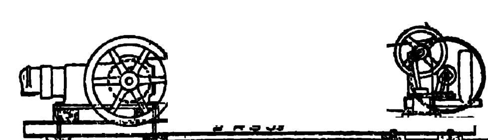


Fig. 5 FOUNDATION FRAME FOR BELT-DRIVEN PUMP

The time required will depend on the size of the block. A 10 B.H.P. engine can be placed on its block after four days if time presses, but seven days should be allowed if possible. The use of rapid-hardening cement will reduce the minimum time to two days. The holding-down bolts and plates can then be placed in position, and the engine put on its foundation. The engine must then be carefully levelled up by inserting thin iron wedges under the bed, using a spirit level on the crankshaft and side shaft.

The nuts can be screwed on the bolts, and the bolt-holes should then be filled with a grouting of one part cement and two parts sand, being made thin so that it flows easily.

When the holes are filled, the grouting can be allowed to flow all over the top of the foundation to grout in the engine bed, and this is generally done by placing boards round the top of the block forming a ledge the height required.

Some engine beds are provided with grouting holes, to enable the grout to be poured inside the bed as well.

The iron wedges used for levelling up the bed should not be removed, and the grouting should be given from two or four days to set before the nuts are tightened and the engine is run. Also, the engine should not be run until the foundation is properly finished and all loose material removed.

An alternative method which can be used for engines up to (say) 100 H.P. is to place the engine, with holding down bolts, in its correct position over the excavated foundation pit. The engine is supported on R.S.Js. and the lower ends of the bolts attached to a stiff wire or strap iron template. The shuttering is then placed in position and the whole concreted in. This is a very quick method as it is unnecessary to wait for the concrete to set before placing the engine on the bed. The R.S.Js. on which the engine is supported reinforce the concrete foundation.

11. Faulty alignment of bearings is a frequent cause of shaft failure, and in any case causes excessive wear and heating of bearings.

When a new engine is being erected, the crankshaft will have been accurately bedded on its main bearings at the makers' works, and it should therefore only be necessary to align the outer bearing correctly.

This may be done by fitting semi-circular pieces of sheet metal inside the lower halves of the bearings, with the centres marked on them, then stretching a piano wire through the centres of the bearings to check the alignment.

If the fly-wheel is keyed on to a crankshaft which extends through the outer bearing, so that the latter can be adjusted to the shaft with the flywheel removed, which is often the case

with horizontal oil engines, the foregoing is the best way of obtaining the accurate alignment.

In most cases, however, with vertical engines large enough to require outer bearings on separate pedestals, the flywheel and an extension shaft are bolted into a coupling on the crankshaft. In this case the weight of the flywheel must be taken by jacks, wedges or a crane, when it is not taken by the outer bearing, and owing to the spring of the shaft, accurate alignment cannot be obtained under such conditions.

In this case the method explained in Sec. **102** should be adopted for obtaining accurate alignment :—

With the weight of the flywheel supported by jacks, &c., the outer bearing (which has already been bedded on to the shaft) is placed on its pedestal, packed up with steel wedges as close to the correct alignment as possible. The jacks are then removed, and the bearing allowed to take its weight.

Turn the shaft until the crank nearest the flywheel is on top dead centre. Gauge the distance between the webs, as shown in Fig. 6, with a crankshaft alignment indicator.

ALIGNING OUTER BEARINGS

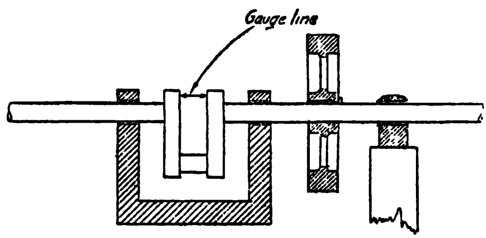


Fig. 6.

Next slack off the bearing cap, turn the shaft through 180°, clamp down the cap and again gauge at the same points.

If the outer bearing is out of true, webs will open and close, causing the two readings to differ.

If a smaller reading is obtained with the crank on top centre, the outer bearing is too low, and vice versa. The amount of out-of-alignment will be approximately half the difference between the readings, but depends largely on the proportions of the engine dimensions.

The flywheel is again packed up, and the necessary adjustment made to the level of the bearing. The test is then repeated until the error does not exceed ·001 inch.

Before finally securing the bearing, test the bedding of the shaft in it by means of marking black on the journal. One end of the bearing may still be low, the weight being taken by the other end only. This must be corrected by packing up,

and the gauge readings checked again. Lateral alignment can be checked at the same time.

The above method takes time, but is the only reliable method of aligning the outer bearing of a heavy engine, such as a Diesel.

The correct alignment having been obtained, the pedestal can be grouted in and in due course nutted down, as described for the engine bed.

12. A 4-inch to 6-inch concrete floor will do much to reduce vibration and movement, as it acts as a sort of raft.

It must be borne in mind that although concrete foundations are necessary for permanent and semi-permanent foundations, oil engines, if required to be installed hurriedly, may quite safely be bolted down to timber baulks or railway sleepers embedded in the ground. Single cylinder engines up to 150 H.P. have been thus mounted.

Provision must be made, however, to prevent the engine and machine moving out of alignment by joining the timber foundation of the engine to that of the machine by a strut (*e.g.* R.S.Js.) placed as nearly as possible under the belt, as shown in Pl. **119**, Fig. 5.

Pl. **119**, Fig. 3, shows a convenient form of foundation for a saw in a forest mill, driven by a portable steam engine.

Pl. **119**, Fig. 4, shows a foundation frame for a direct-coupled turbine pumping set.

In each case the foundation frame is merely buried in the ground.

PART III.—APPLICATION

CHAPTER XXXII

TRANSMISSION OF POWER

147. *Principles of transmission*

1. **Direct-coupling.**—The most efficient method of transmission of power is by direct-coupling. This method can only be used when there is at least one speed which is economical for both prime mover and machine.

When the speed ranges make direct-coupling possible, it can be done in several ways, viz. :—

i. By using the same shaft for engine and machine, *e.g.* railway locomotives have the driving wheels on the crankshaft of the engine, and the rotor of an electric generator may be on an extension of the crankshaft of an engine.

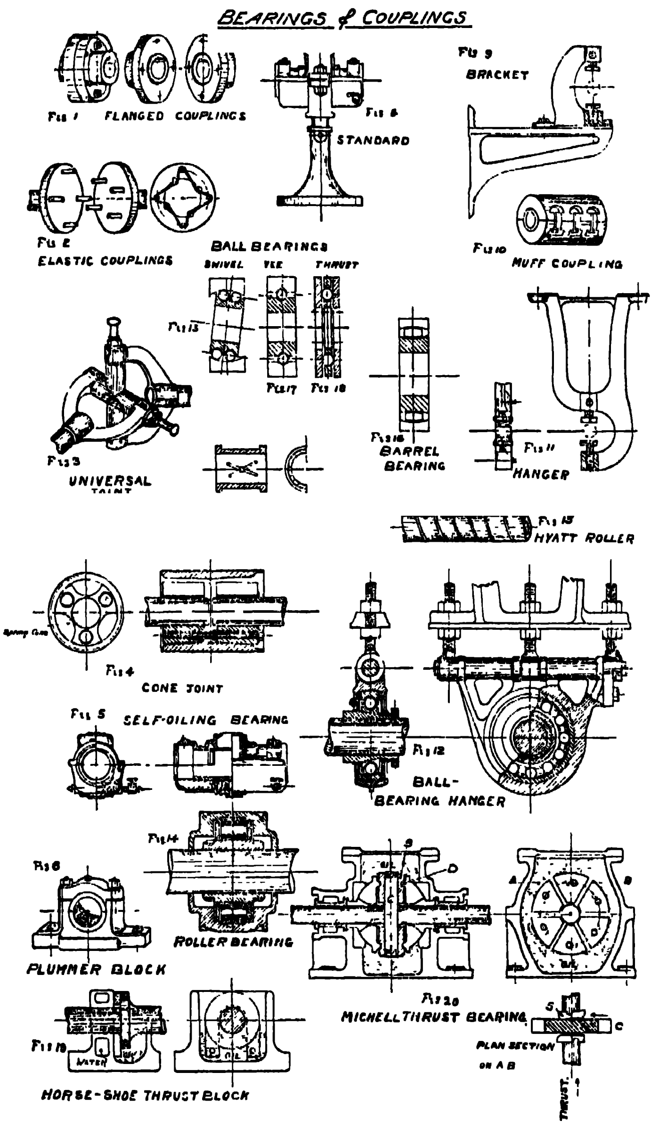
ii. When absolute alignment can be ensured, the shafts of the engine and machine can be rigidly coupled by a pair of flanges, driven on to the ends of the shafts and prevented from revolving by means of keys driven tight. The flanges are then bolted together, usually with countersunk or recessed bolts to eliminate danger to attendants, Pl. **120**, Fig. 1.

iii. When alignment can be ensured, but it is required to start the engine without load, by some form of clutch which can be thrown in or out of action while the shafts are revolving. Some forms of clutch are described in Sec. **150**.

iv. When alignment cannot be absolutely ensured, or where either the engine or machine is liable to sudden fluctuations of speed which must not be communicated too suddenly to the other, a flexible coupling is necessary, such as that shown on Pl. **120**, Fig. 2, a leather lacing threaded between studs protruding alternately from the driving and driven flanges.

v. When alignment cannot be maintained, as in a motor-car whose power unit is carried on a sprung frame, while the axle is rigidly coupled to the road wheels, a flexible shaft is necessary, containing at least one universal joint, which permits free bending in any direction while transmitting the drive positively *i.e.* without slip. Pl. **120**, Fig. 3, illustrates a universal joint.

PLATE 120.



[*Fig.* 12 *reproduced by permission of The Hoffmann Manufacturing Co., Ltd., Chelmsford, Essex.*]

2. Various methods of transmission.—For transmitting power from one shaft to another, a choice must be made from the following :—

i. A leather or canvas flat belt running upon crown-faced pulleys, which is the type of drive most frequently used in workshops.

ii. Ropes running in grooved pulleys. Since each rope takes its share of load, any amount of power can be so transmitted by adding more ropes.

iii. Chains, running on toothed sprockets; a very powerful and positive drive, expensive, and inclined to be noisy, but highly efficient.

iv. Toothed gear wheels, which can be made to transmit any load at almost any speed; expensive when made for fast running. Gears can only be used when the shafts can conveniently be placed close together, preferably parallel, and very rigidly held.

v. Friction gear wheels; only suitable for comparatively light loads at high speeds.

vi. Worm and worm-wheel; suitable where a large reduction of speed is required, and the shafts can be placed at right angles.

vii. Electric transmission; the prime mover drives an electric generator, and the current is transmitted to a motor, which drives the machine. Expensive and frequently of low efficiency, but extremely convenient, especially if the power has to be transmitted a long distance, or if the machines have to be portable.

viii. Pneumatic transmission; the engine drives an air compressor, and the air is piped to a pneumatic motor. Efficiency very low indeed, but very useful for portable tools, especially of the percussion type, for which pneumatic power is more easily used than any other form.

ix. Hydraulic transmission. Expensive, but very useful when high pressures are required at low speeds, as in a forging press.

148. *Line shafting and plain bearings*

1. Shafting.—*Workshop system.*—The means normally adopted for transmission in workshops are :—

i. An engine or motor drives a line shaft by means of belts or ropes, running on pulleys of large diameter.

ii. Machines are driven from the line shaft, nearly always by means of belts, but occasionally by ropes or chains, at speeds to suit the work of each one.

Strength of shafting.—Shafting is usually of mild steel, sometimes hollow for lightness, supported at frequent intervals by bearings, which must be capable of very accurate alignment, or the shafting will be strained and a large frictional loss will occur. The shafting must be strong enough to bear the continually alternating bending strain produced by its weight and that of the pulleys on it, and also by the pull of the belts, as well as the torque necessary for transmission of power and the unknown stress due to vibration.

The following is a reliable empirical formula for the diameter, D, necessary for mild-steel shafting to transmit a definite horse-power, H.P., at a stated number of revolutions, N, per minute :—$D = 3{\cdot}75\sqrt[3]{\frac{\text{H.P.}}{N}}$ (inches). The greatest unsupported length of shafting between bearings should not exceed $60\sqrt[3]{D^2}$ (inches). This is generally the ruling factor in selecting shafting suitable for a particular shop.

Unnecessary stresses and frictional loss should be minimized by great care in the selection of suitable bearings, in accurate alignment, and by reducing the weight of pulleys and the tightness of belts to the lowest figure consistent with safety and efficiency. Normal speeds for workshop line shafting are from 200 to 300 revolutions per minute.

2. **Rigid couplings.**—When two or more lengths of shafting must be coupled, a flange joint, as described in Sec. **147**, para. 1 (ii), may be used.

The muff coupling shown on Pl. **120**, Fig. 10, is simpler. The muff may be split or not. It may be solid if the shafting can be slid apart to enable it to be put in place, but this is seldom possible.

The cone coupling shown on Pl. **120**, Fig. 4, is well known under the name of the *Universal* coupling. The inner spring cones are slipped each on one shaft end, and are then drawn together into the double-ended female cone which forces them to grip the shaft ends. A feather may be added if desired for extra security. All bolt-heads must be shrouded or sunk.

3. **Qualities of shafting.**—Mild steel shafting can be obtained of widely varying qualities, and the cost naturally varies with the quality.

If shafting is held in rigid bearings, only the best quality of turned shafting can be used with success. Such shafting loses its accuracy and its value if roughly handled in transit, if heavily strained when in use through being mounted in incorrectly aligned bearings, or if overloaded with heavy pulleys or too tight belts.

Bright drawn or rolled shafting can be obtained at a lower price; if carefully examined and selected, it is good enough to use in swivelling bearings. When swivelling ball bearings are used, accuracy is of little importance, provided the inner races can be slipped along the shaft, and drawn shafting is accurate enough, except for very high speeds such as are only used for grinding machines.

Black shafting is inaccurate, and only suitable for use with ball- or roller-type bearings with full allowance for swivelling.

4. **Plain bearings.**—*Design and materials.*—Plain shaft bearings are usually of cast iron, and their length is from three to four times the diameter of the shaft. They should be capable of swivelling freely in any direction; this is usually attained by holding the bearing between two vertical screws with cup ends. They engage two portions of the outside surface of the bearing casting, which are turned to form part of a sphere whose centre is in the centre line of the shaft, Pl. **120**, Figs. 5 and 9. There should be some means, either in the bearings or in the brackets which carry them, for adjusting their position both vertically and horizontally.

When erecting the shafting it is of great importance that all bearings should be brought truly in line, otherwise much power will be lost in unnecessary friction and the bearings may run hot.

Bearing pressures.—For self-oiling cast-iron bearings the maximum pressure per square inch of projected area should not exceed 50 lb., *i.e.* the greatest likely load on the bearing, including weight of shafting and pulleys and the resultant of belt pulls, divided by the product of the diameter and length of the shaft journal must not be more than 50 lb. In case of necessity this pressure can be increased, but then the bearing must be lined with brass or white metal, when it may be allowed to take pressures of 60 lb. and 80 lb. respectively per square inch of projected area. If the old plummer block type of rigid bearing (Pl. **120**, Fig. 6) is used it should be lined, and the pressure kept below 50 lb. per square inch for white metal linings and 40 lb. per square inch for gun-metal.

All the above figures allow a high factor of safety with the object of allowing for unknown factors, such as overtight belts, lack of alignment, &c.

Lubrication.—The efficient lubrication of all bearings is of the utmost importance, but is seldom achieved unless an automatic device is fitted, together with an ample oil reservoir. The cost of such self-oiling bearings is about equal to that of a plain bearing and an oil-cup. Therefore, in all new work none but self-oiling bearings should be installed.

If old-type bearings are in stock they may safely be used, provided that large oil-cups are fitted in prominent and accessible positions, and that some individual is personally responsible for keeping them filled and working when the shafting is running. Their consumption of oil is very heavy.

Friction losses.—The horse-power lost in shaft friction, with swivelling bush bearings and ring lubrication may be calculated roughly from the formula :—

$$F = \frac{NLD^3}{80{,}000}$$

N = r.p.m., L = length of shaft in feet, D = diameter of shaft in inches.

Imperfect lubrication or untruth in the shafting will increase the friction enormously, probably to ten times as much or more in very bad cases.

On the other hand, if ball bearings are used, the loss should not exceed one-tenth of the value given by this formula.

Oil sumps.—The oil is eventually squeezed out of the ends of the bearings and drips down. An enclosed sump should be provided to collect this used oil without allowing it to gather dust from the air, and also some device, such as a ring, to lift the oil and replace it in the oil grooves, Pl. **120**, Fig. 5.

The sump should contain about one pint of oil per 50 square inches of projected bearing area. The rings must dip well below the surface of the oil, and must rest upon a portion of the shaft left bare for that purpose, and upon that alone. Filling and draining plugs or cocks are necessary. The oil should be kept up to the correct level by frequent inspection, and should be changed at least twice a year.

5. **Brackets, hangers, and standards.**—Bearings for shafting may be carried on standards, on brackets fixed to a wall, or on hangers fixed to girders overhead, as shown on Pl. **120**, Figs. 8, 9, and 11 respectively. In any case it is essential that the wall or girders shall be stiff and well supported; otherwise, excessive vibration would be caused and the structure might even collapse.

Wall brackets should not be fixed to any brick wall unless it is at least 1½ bricks thick and supported by suitable buttresses or party walls. Head room of at least 7 feet must be left under all belts beneath which men can walk.

Brackets, &c., are usually of cast-iron, and they should be of solid design throughout, well webbed, and rounded at all corners as shown. The bolt-holes in brackets, &c., should all be slotted, so that after rough erection they can be brought truly in line before finally tightening up.

6. Underfloor shafting.—It is usual in wood-working shops to place the shafting in a pit beneath the floor level. The same principle may be followed in other shops, but it is not always possible with old machinery.

This system simplifies lighting and also the guarding of belts. It is essential that every portion of the pit should be capable of being opened up for inspection. The pit must be kept perfectly clean. It should be lined with brick or concrete, with a gutter leading out to an earth pit, which must not communicate with any ordinary drainage system, since oil may be carried out, and may clog drains or cause fire or explosion in them.

The shafting is best carried on low standards in this case.

7. Laying out line shafting.—It is essential that line shafting should be laid out carefully, since any inaccuracy causes great loss of power, difficulty in keeping bearings cool, and in keeping belts on their pulleys. Much inaccuracy may result in a broken shaft.

i. The position of the first and last bearings should be selected carefully, so that the shafting will be parallel to the walls. These positions should be marked by half driving two large flat-topped nails into the floor precisely under the centres of the intended positions of the bearings. If a level can be obtained, these nails should be made precisely level, by setting up the level about midway between them, sighting on to a staff placed upon the top of each nail in turn, and driving in the higher one as necessary.

ii. A chalked line should be stretched tightly between these nails, and *snapped* to mark the centre line upon the floor. Other nails can then be lightly driven in on this line to mark the centres of all the other bearings. They should then be checked by sighting along them to ensure no large inaccuracy.

iii. Each nail in turn should be driven in carefully to the same height as the end ones, either using the level and staff, as in (i), or three boning rods, one on each end nail and one on the nail to be adjusted.

iv. The projections of the centres can now be marked upon the girders or wall, their positions being ascertained by means of a plumb-bob suspended over each nail in turn. In the case of wall brackets, a large square should be applied to the wall, at the correct height, and brought up to touch the plumb-bob string.

v. A long straight-edge should then be laid across each pair of the centre marks on the girder or wall in turn, and a line drawn to mark the centre line of the shaft; then a line should be drawn at right angles, to mark the centre line of the bracket or hanger, using a square to ensure accuracy.

vi. A template of sheet metal or wood should be prepared, of precisely the form of the footing of the brackets or hangers, with bolt-holes drilled, and centre lines marked. This template can then be applied to each marked centre in turn, and the outline and bolt-holes marked upon the wall or girder. Each bolt-hole centre should be surrounded by two circles, one the same diameter as the bolt and the other considerably larger, especially in the case of wall brackets, since the brickwork may become damaged for some distance round the hole, and the outer circle should remain as a check upon the accuracy of the position of the hole.

8. **Erection and overhaul of line shafting.**—When first erecting line shafting and when subsequently overhauling it, each bearing should be fitted, as described in Sec. **37**, para. 9, to the portion of the shaft which will run in it.

The bearings will normally be too far apart to line up with a straight-edge.

The lining up may be done roughly by stretching a string through the bearings to obtain lateral position. Vertical adjustment cannot be effected by means of a string, since it will sag, however tight it may be.

Vertical adjustment can be roughly obtained when first erecting, by placing a rod upon each locating nail in the floor, in turn, and bringing the centre of the bearing or, better, the bottom of a length of shafting placed in the bearing to a standard height, marked on the rod.

Lateral adjustment is generally provided by slotted holes in the hangers, or plummer blocks in the case of wall brackets, which permit a small lateral movement when the holding-down bolts are slack.

Vertical adjustment is generally provided in swivelling bearings by means of cup-screws. If such bearings are not provided, packing must be used between the hangers and girders, or between the plummer blocks and wall brackets.

If a length of shafting can be obtained long enough to bridge three bearings, accurate alignment can be ensured finally, as follows :—

i. Assemble the bearings, placing strips of thin metal between the halves to separate them slightly.

ii. Select a sufficiently long piece of shafting to bridge three bearings, and test its straightness by rolling it on the bed of a large lathe or the ways of a planing machine. The selected piece is then used as a straight-edge.

iii. Place the selected piece of shafting in the bearings, and slide it along from bearing to bearing ; it should pass easily into each. Any lack of alignment will be plainly indicated and should be corrected, half the correction being

made in the bearing the shaft will not enter and half in the previous one.

iv. Work backwards in the same manner, and make any further adjustment. If necessary, continue working forwards and backwards until there is no appreciable error.

v. Remove the packing strips mentioned in (i) and pass in the whole line shafting. Any difficulty in sliding in any piece will indicate that the length of shafting concerned is bent. It should be straightened as described in Sec. **106**, para. 1.

vi. Tighten together all the half-bearings. Test whether the shaft will revolve without unreasonable force, *e.g.* one man should be able to revolve it by pulling round the rim of a medium-sized pulley upon the shaft.

vii. Ensure that all bearings are properly supplied with lubricant, and run the shafting light for at least an hour before placing any belts upon the line pulleys, watching carefully whether any bearings are running hot. If a bearing runs hot, it should be opened slightly. The halves should be taken out, and scrape down where bright spots show that the pressure has been too heavy.

9. **Alignment of pulleys.**—Belts will not run satisfactorily on pulleys which are not truly in line. Lack of parallelism between countershafts, machines, &c., and the main line shafting causes the belt to run towards one side, and the belt will generally leave the pulley.

Lack of alignment of the centre planes of the pulleys has generally less effect, and the belt will normally remain on the pulleys, but indicates the error by running on opposite sides of the pulleys.

Pulleys may be roughly located by stretching a string from a nail in the wall or roof to one on the floor beyond a machine, and squaring it to the shaft by means of a large square, the limb of which, along the string, should be not less than three feet long. The sides of both pulleys should touch the string at nearly opposite points.

Before a machine is grouted in, or before a countershaft is finally bolted to the girders, two long straight-edges should be placed against the sides of the pulleys. Any lack of parallelism or alignment can be seen by sighting along the outer edges.

149. *Ball, roller and thrust bearings*

1. **General principles of ball and roller bearings.**—Ball bearings may be fitted with advantage for light fast-running machinery, especially where power is expensive. Pl. **120**, Fig. 12, shows a ball race adapted for a shaft bearing. Ball bearings are more expensive than plain bearings, but the

frictional loss is considerably reduced, being only about one-tenth of that in even well-oiled plain bearings with ring lubrication. Moreover, the friction at starting is no greater than when running.

2. **Swivelling devices.**—Free swivelling and correct adjustment for line are absolutely essential, as any inaccuracy may lead to the complete breaking up of the bearing.

Several types of ball bearing are on the market in which swivelling is allowed in the bearing itself. Pl. **120**, Fig. 13, shows one in which this is attained by grinding the outer race so that its inner surface is a portion of a sphere. The inner race should be free to slide upon the shaft, since this type of bearing must not be allowed to take any end thrust.

3. **Loads of ball races.**—The crushing strength of a hard steel ball between flat surfaces is about $90{,}000d^2$ lb., where d is the diameter of the ball in inches ; but a very large factor of safety is necessary, which increases rapidly with the speed at which the bearing is run. The formula $P = KNd^2$ pounds has been found to give a safe working load on a radial bearing containing N balls of diameter d inches, where K is a coefficient depending upon the shape of the groove in which the balls run and upon the speed.

For normal-shaped grooves whose radius is $\frac{2}{5}d$, the following table gives K for various speeds in revolutions per minute :—

R.p.m.	1	10	100	150	200	300	400	500	1,000	2,000	3,000	10,000
K	600	468	400	377	343	312	290	273	203	156	126	65

For balls running on flat surfaces or in spherical outer races, these coefficients should be halved.

4. **Lubrication.**—The efficient lubrication of ball bearings is of great importance. For slow-moving bearings a pure mineral grease is best, as it is easily retained. For high speeds a mineral oil of medium viscosity should be used, and it should be supplied freely, if possible, by running the bearings submerged or partially so. In every case, dust should be excluded by completely encasing the bearings in light metal caps or covers containing felt washers, such as those shown on Pl. **120**, Fig. 12. The balls are often held in a moving cage ; this is convenient for assembling, but may reduce the number of balls.

5. **Roller bearings.**—To carry loads which are too heavy for ball bearings of a reasonable size, roller bearings may be used, Pl. **120**, Fig. 14.

The permissible load is about 1,000d lbs. per inch length of any one roller of hardened steel of d inches diameter.

For a fast-moving radial bearing, containing N rollers of hardened steel of diameter d and length L inches, the safe load may be taken as 300NdL lbs. under ordinary conditions. Large slow-moving bearings have run satisfactorily up to 20,000NdL lbs. load.

Roller bearings do not run well if their length much exceeds their diameter, unless some means is provided to keep them parallel to the journal. A bearing of any desired length can be made by placing two or more rings of short rollers side by side, the rings being separated by steel washers.

In the Hyatt roller bearing, Pl. **120**, Fig. 15, each roller is a helical steel spring, ground true. A slight departure from the parallel position merely bends these rollers, and they run satisfactorily even when of considerable length.

6. **Barrel bearings.**—A more recent introduction is the barrel bearing, Pl. **120**, Fig. 16, which occupies a middle position between ball and roller bearings. The races are ground slightly hollow, and the rollers are tapered to both ends, producing a slightly sharper curve in longitudinal section than that of the races.

The area of contact between a ball and a flat bearing may be considered to be a circle, and that between a roller and a flat bearing as a narrow rectangle. The area of contact between a barrel and its nearly equally curved race may be said to be an ellipse, whose short diameter is the same as that of the area contact of a ball of the same diameter as the barrel. The long diameter of the ellipse is the same as that of the area of contact of a ball whose radius is equal to that of the barrel curve, and this can be made very large.

The formula for ball bearings can be applied to find the safe load in the form $P = KNDd$, where d is the actual diameter of the barrel and D is twice the radius of the barrel curve in section. Barrels run perfectly truly and, as the formula shows, will carry much more weight than balls of the same diameter.

7. **Ball thrust bearings.**—Radial ball bearings with deep grooves can resist small longitudinal thrusts without damage.

A special type of radial ball bearing with grooves of V section, Pl. **120**, Fig. 17, will stand a longitudinal thrust of $KNd^2 \sin A$, where A is the inclination of the side of the V groove to the centre line of the journal.

Cone bearings, or more accurately combined thrust and radial ball bearings, as fitted in most bicycle wheels, are generally designed to take about equal thrust and radial stresses.

Thrusts too heavy to be met by either of the above methods may be taken on thrust washers, Pl. **120**, Fig. 18. The pressure that can be carried safely if grooved races are fitted is $3KNd^2$, and where flat plates are used it is $1{\cdot}5KNd^2$. It is very necessary that the thrust should be borne equally by all the balls. It is advisable, therefore, in all important ball thrust bearings to take the thrust finally upon a spherical seating, so that the stationary race can swivel slightly.

8. **Thrust collars.**—In ordinary shaft lines the small longitudinal thrust necessary to keep the shaft in place can be taken upon a plain collar placed on the shaft close to the end of a bearing, as at both ends of the countershaft shown on Pl. **123**, Fig. 4.

Such a device can only carry very small loads, since lubrication is impossible.

If such a collar has at least one segment cut out of its surface, or that of the block against which it bears, and effective means is provided for constantly spreading oil upon the segment of the surface thus laid bare, the oil will be carried into the bearing.

Such a thrust collar can be made to carry 50 lbs. per square inch.

The old-fashioned horseshoe thrust blocks on marine propeller shafts, Pl. **120**, Fig. 19, worked upon this principle; but it was difficult to keep them cool even by copious water cooling, and the frictional loss was heavy, varying from 2 to 30 per cent., according to conditions of load, lubrication, and temperature.

9. **Michell thrust bearings.**—Heavy longitudinal thrusts, such as that of a ship's propeller shaft, the unbalanced thrust of a turbine, or any heavy machinery upon a vertical shaft, may be taken effectively upon a thrust bearing of the Michell type, Pl. **120**, Fig. 20. In these, a wide collar, C, upon the shaft bears upon a ring of thrust block segments, S, each of which can rock independently upon a fulcrum or knife edge, D, which is applied to the back of the block either at its centre in the case of reversible machinery or preferably a little farther from the leading edge where the direction of revolution is constant. A space is left between each block to permit oil to reach the face of the collar. The leading edge of each block is rounded, so that it slides up on to the oil film much as a sledge rides up over snow. In operation the pressure increases uniformly from the leading to the trailing edge, and the oil film is gradually squeezed out by this increasing pressure, but it must not be destroyed before it is past the block. Since this is a matter of time, a rapidly-revolving bearing can carry a heavier load per square inch than a slow-moving one.

The whole bearing should be immersed in oil, which must be liquid enough to make certain of reaching the small lubricating strips of bare collar.

A load of 500 lbs. per square inch can be carried safely and economically, the coefficient of friction being about 0·002 under full load and nearly independent of load and speed, except at starting, when, until the speed in high enough to produce the correct oiling effect, the coefficient is about 0·02.

The ordinary thrust block will not carry a load exceeding 50 lb./sq. inch and its coefficient of friction exceeds 0·02, that is, ten times that of the *Michell* thrust block.

150. *Clutches*

1. **Positive clutches**.—When a length of shafting is to be coupled occasionally to another or to a pulley which is normally freely mounted on it, and both can be stopped to effect the coupling, a simple dog clutch of the type shown on Pl. **121**, Fig. 1, can be employed. The drive being absolutely rigid and positive, the clutch must not be thrown in unless the shafts are at rest or revolving at the same speed. The sliding sleeve, S, is free to move longitudinally, but is prevented from revolving on its shaft either by a feather, F, or by a square formed on the shaft.

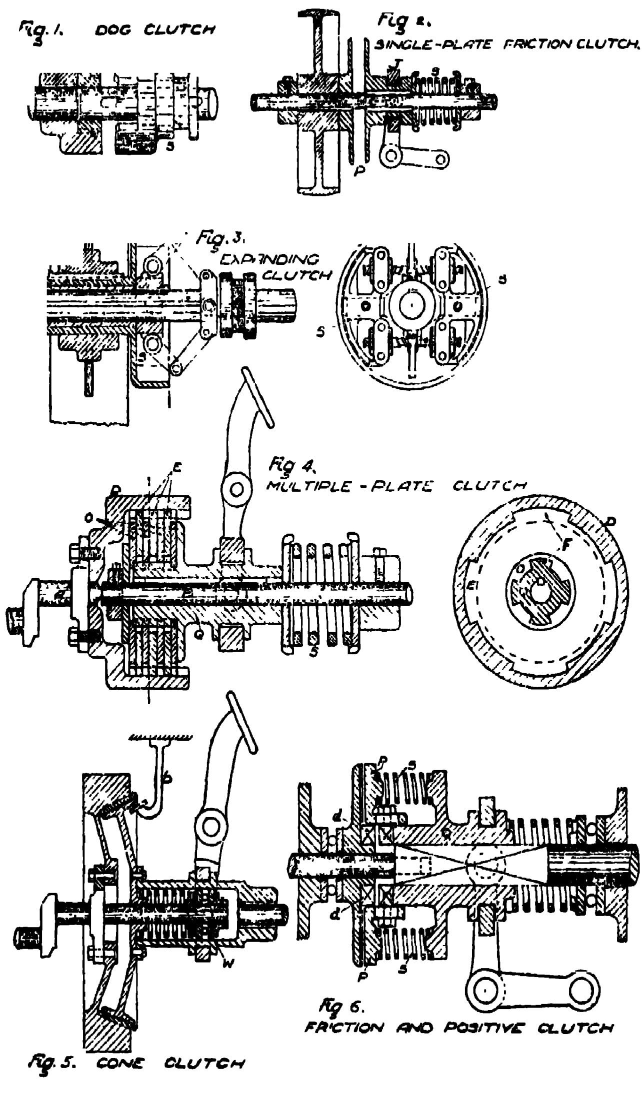
2. **Friction clutches**.—Friction and other non-rigid clutches are intended to be capable of being thrown in without undue shock while one shaft is revolving and the other is stationary, and to absorb shocks by slipping a little when they occur. They may be of several types :—

i. *Single-plate clutches* consist of two single disc plates, P on Pl. **121**, Fig. 2 (which may be of different metals, or one may be faced with leather, fibre, or special composition), one of which can slide longitudinally. They are usually kept in contact by a spring, S, and may be thrown out of gear by means of a jaw, J, working in a circular groove in the hub of the sliding disc.

ii. *Multiple-plate clutches* consist of several discs, of which all odd numbers, O on Pl. **121**, Fig. 4, are keyed to a quill, Q, on which they fit, by feathers, F, which prevent them from revolving on it, while allowing them to slide longitudinally. All even numbers, E, are similarly keyed on their outer edges to a drum, D, fixed to a shaft, A. These plates are kept jammed up close by a spring, S, but can be released from pressure by means of a jaw and collars on the quill. The quill is free to slide longitudinally, but is prevented from turning on the shaft, B, by a feather. The grip of the plates may be increased by forming circular corrugations in their

PLATE 121.

TYPES OF CLUTCHES.



surfaces, which increases the surface in contact and produces a certain amount of jamming.

iii. *Band clutches* consist of a drum, rigidly keyed to one shaft, and a band, generally carried on a plate or hollow drum on the other shaft. They are actuated by tightening the band on the drum which it encircles.

iv. *Expanding clutches* may be of the band type, where the band is stiff, and placed inside the drum. They are actuated by uncoiling the band and so expanding it against the inner surface of the drum.

Frequently, instead of one continuous band, two or more segments, S on Pl. **121**, Fig. 3, are provided, all of which are simultaneously expanded by means of some device, such as a cam plate or a series of toggle levers, L.

v. *Cone clutches* are merely a variation of the plate clutch, in which a better grip is obtained by substituting for the plates a pair of cones, one of which is forced into the other by a spring, Pl. **121**, Fig. 5.

Cone clutches may also be multiple.

vi. *Combined positive and friction clutches* consist of any type of friction clutch and a dog clutch, which does not come into operation until the plates, &c. are already firmly engaged.

On Pl. **121**, Fig. 6, the first movement of the sliding quill, Q, forces the friction plates, P, together, acting through the springs, S. Further movement of the collar causes the dogs, *d*, to engage. Thus a comparatively light friction clutch can be made to start up a shaft running light. When it is running the dog clutch can be thrown in, and a load can then be taken without slip.

3. **Magnetic clutches.**—Magnetic clutches are normally of the single-plate type, an electro-magnet being incorporated in one of the plates to produce adhesion and the torque is transmitted by friction.

Magnetic clutches have the advantage that they can be controlled from a distance. The normal attractive force is about 100 lb. per square inch of magnet-pole area.

4. **Hydraulic clutches.**—Hydraulic transmission from one shaft to another may take one of the following forms :—

i. A plate or drum carrying one or more plunger pumps operated by an eccentric on the shaft. Any relative movement of the shaft and drum causes oil or water to be drawn from a reservoir and driven back again through an open control valve. On closing the control valve, the plunger is prevented from working and the relative movement cannot take place. The barrel is then carried round with the shaft. This constitutes a hydraulic clutch, which can be made very gentle in its action by designing the control valve so that it can only be closed gradually.

ii. The driving shaft may be made to work a hydraulic pump, the pressure liquid from which drives a hydraulic motor upon the driven shaft.

The pump plungers may be operated by an eccentric of variable throw. By centring the eccentric no power is transmitted, and by increasing the throw gradually any desired ratio of velocities between the shafts may be obtained. This constitutes not merely a very gradual clutch, but also a variable gear.

iii. The same effect may also be obtained by driving pump plungers placed parallel to the drive shaft, and grouped round it, by means of a plate (called a *Swashplate*) carried on the shaft and capable of being tilted at any angle. The stroke of the plunger, and, therefore, the quantity of liquid delivered, depends entirely upon the inclination of the plate, and the supply ceases when the plate is placed at right-angles to the shaft.

5. **Precautions necessary in fitting clutches.**—*Thrust.*—In every kind of clutch, springs and other controls must be so disposed that any longitudinal thrust upon the shaft is balanced or properly taken upon thrust bearings.

For instance, if a spring compressing a plate clutch, as shown on Pl. **121**, Fig. 2, revolves with the shaft, it should bear at its fixed end upon a collar fixed to the shaft. On Pl. **121**, Fig. 5, the thrust between the cones is taken upon a ball-thrust washer, W, and there is no resultant longitudinal thrust upon the shaft, since both thrusts are taken by it.

Cooling.—Clutches which carry much power develop a large amount of heat if they are allowed to slip for a considerable time. If it is intended to slip a friction clutch, it is necessary to provide for cooling, either by means of air fins, and perhaps also a fan, or by circulating water through some part of the clutch.

Clutch control.—Clutches must be put into action gradually. Otherwise a great stress would be thrown on the clutch and shafting, and some portion of the transmission gear might be broken or the prime mover supplying the power might be stopped. Efficient means must, therefore, be provided for controlling the springs, &c., without difficulty or much effort, by fitting levers, screws, or other gear to ensure that considerable movement is necessary to apply or release the drive, and that only a small force need be applied at the handle or pedal, so that it may be well under control.

Clutch stops.—Where various gears are to be engaged at different times, as in a motor-car, a clutch stop or brake, *b*, should be provided, as shown on Pl. **121**, Fig. 5. Thus, when the clutch is disengaged, the free portion of it can be slowed down or stopped by pressure upon the stop before attempting to engage the teeth of the gears.

151. *Belt, rope and chain drives*

1. **Belts.**—The types of belt in common use are :—

   i. *Leather*, generally a single thickness, but two or more may be cemented and sewn together, to form what are known as double, treble, &c., belts.

   ii. *Canvas*, usually folded longitudinally and the *plies* stuck together with rubber solution or similar composition. Any weight or thickness may be so obtained.

   iii. *Link belting*, usually made of many links of leather or composition held together by steel pins, as shown on Pl. **122**, Fig. 1.

   iv. *Steel belts*, rarely used, consisting of a thin ribbon of spring steel, carefully tempered.

The type of belt most suitable for a drive depends mainly upon the amount of power to be carried, and also upon the permissible size of pulleys and their speed.

Single leather makes the best belt where it can be used. *Double leather* is not very flexible, does not run well on small pulleys or with crossed or skew drives, and it seldom wears well.

Canvas belting, which includes such proprietary articles as *Balata* and various *Hair* belts, can be obtained in any desired strength, and is generally preferred to double or treble leather, since it is more flexible. It does not always last well, and must be kept free from oil. The fastenings require more care than those for leather belting, since the canvas is easily torn.

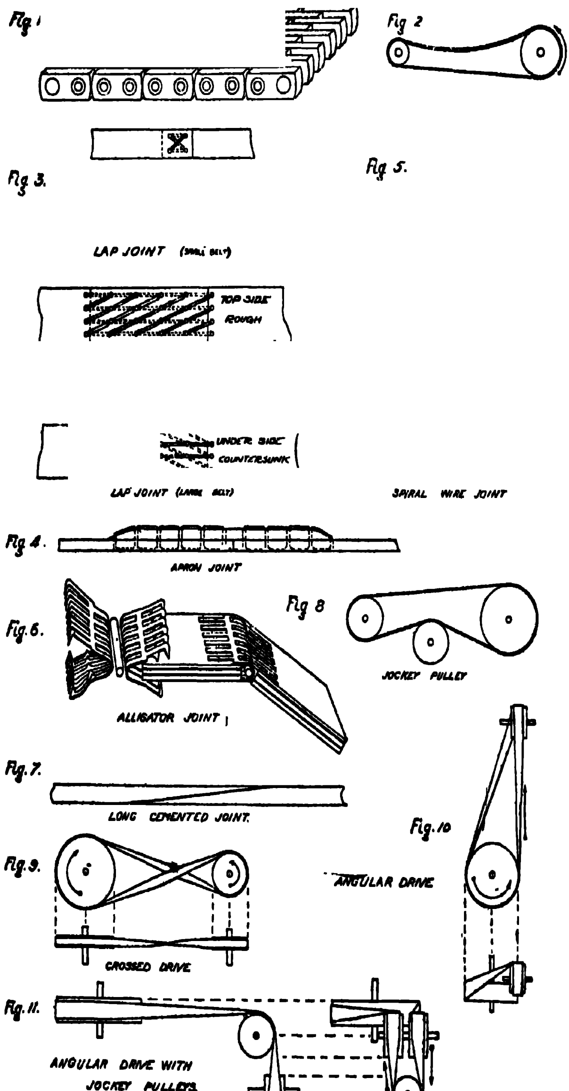
Link belts, Pl. **122**, Fig. 1, are very heavy, but flexible. They are very suitable for drives in which much power is to be carried on small pulleys, such as those of motors and dynamos. They should not be crossed. If striking gear is fitted, very large forks are necessary, and the jaws should carry rollers free to revolve, because the riveted ends of the pins are easily worn or broken off. If this happens the belt will fly to pieces.

Steel belts may be run on bare cast-iron pulleys, or on cork- or fibre-covered pulleys. They will carry a large amount of power upon comparatively small pulleys, but require great skill to make joints in them and special tightening appliances.

2. **Speeds.**—Steel belts are normally run at any speed up to 10,000 feet per minute; other belts run satisfactorily at speeds up to 3,000 feet per minute; they may be run at 5,000 feet, but at a considerable loss in efficiency, unless pulleys of very large diameter compared with the belt thickness are used, because centrifugal force tends to make the belt fly out and reduce the arc of contact with the pulley.

PLATE 122.

BELT TRANSMISSION



3. **Power transmitted.**—The part of a belt which transmits power is tight, while the other part is comparatively slack and merely keeps up the circuit. The slack side should be as loose as possible without slipping; it should be on top, since its sag then increases the arc of contact, Pl. **122**, Fig. 2.

If the tensions in the tight and slack parts are T and t lb. respectively, then the effective pull is $(T - t)$ lb., and the horse-power transmitted at a belt velocity of V feet per minute is $\frac{V \times (T - t)}{33{,}000}$. For a well-designed drive giving a minimum arc of contact of about 140° on the smaller pulley, $(T - t)$ is about 45 lb. per inch width of average $\frac{3}{16}$ in. single leather belt and 75 lb. for double leather. For canvas belting $(T - t)$ is generally a little higher than for leather of the same thickness, especially in thick belts, but it varies very much with the quality of the belting.

In the case of link belts $(T - t)$ is about 88 lb. per square inch section of the belt. For steel belts it is about 16,000 lb. per square inch.

4. **Compounded belts.**—If a belt should prove insufficient to carry the load, as a result, for instance, of adding more machines in a shop, another belt may be placed upon the existing one. The tension of the belts should be carefully equalized.

Leather belts thus compounded run well, and the outer one transmits about 70 per cent. of the power that it would do if used alone.

5. **Joints.**—Leather belts may be fastened by overlapping the ends, and either lacing or riveting them together, Pl. **122**, Fig. 3. They may also be butted and joined by an apron on the outside, Pl. **122**, Fig. 4. The ends of a lap joint or apron should be scarfed down to obviate sudden changes of thickness.

Many types of metal fasteners are obtainable. They are quick to fix, and satisfactory for slow and medium speeds provided they are light and short. A plate joint should be hinged in the middle to diminish the length of rigid plate.

A spiral steel-wire joint with a raw hide hinge pin, as shown on Pl. **122**, Fig. 5, is light and flexible, suitable for high speeds, but has only about two-thirds the strength of a good lap or butt laced and cemented joint.

A good type of joint, known generally as the *Alligator*, consists merely of a hinge, each plate of which is double and each half-plate has projections inwards, Pl. **122**, Fig. 6. It is simple to fix, the operation consisting merely of placing the ends of the belt between the double plates and then closing them together.

Light fast-moving belts should always be fastened by a long diagonal scarfed joint, as shown on Pl. **122**, Fig. 7, cemented with a mixture of fish glue and isinglass in equal parts, with enough warm water to dissolve the isinglass. This gives an ideal joint, with the minimum of stiffness and weight, and which runs silently at all speeds.

Short scarfed joints for heavier belts may be cemented with advantage, and also laced. Donkey hide is much favoured for laces owing to its toughness. The lace should be countersunk into the inner surface of the belt by cutting shallow grooves between the holes, *see* Pl. **122**, Fig. 3. These grooves must be longitudinal and never across the belt, because the latter would seriously weaken the belt.

6. **Belt dressings.**—Leather belts must be kept supple, and their surfaces should be clammy, so as to cling to the pulleys. This is best ensured by rubbing in tallow, which may be thinned with a little oil in cool climates. Canvas belts must not be greased.

Various sticky compositions are on the market, which greatly increase the clinging power of a belt if constantly applied. If such compositions are once applied the practice must be continued, because the composition dries hard in process of time and a belt will slip badly unless fresh is added.

Bricks of resinous compound are also obtainable, which are intended to be rubbed upon canvas belts. They are effective where belts are not heavily loaded.

7. **General rules for belt drives.**—In designing a belt drive the following rules should be observed; otherwise belts would slip excessively.

i. The distance between pulleys should be as much as is reasonably possible, and never less than three times the diameter of the larger pulley.

ii. The belts should be as nearly horizontal as possible. Where drives must be nearly vertical, belts should be crossed for preference so as to increase the arc of contact, and a belt wider by 50 per cent. than indicated by the formula in para. 3 should be used.

iii. The slack side of a belt should be uppermost, so that its sag may increase the arc of contact.

iv. The ratio of diameters of the pulleys should not exceed six to one, and preferably not more than five to one.

v. The thickness of the belt should not exceed one-thirtieth of the diameter of the smaller pulley. Otherwise the belt would slip and wear out quickly.

vi. If rules (i) to (v) cannot be carried out, a jockey pulley should be fitted, of diameter not less than the smaller pulley, to increase the arc of contact, as shown on Pl. **122**, Fig. 8, or the pulleys should be faced with leather or some suitable fabric to increase the grip.

vii. A new leather belt must be thoroughly stretched before use. This may be done by suspending the belt and attaching weights to it for a week or so. This will obviate the trouble involved in frequent shortening and re-jointing which would otherwise occur when the belt is taken into use.

8. **Losses in belts.**—Provided the rules given in para. 7 have been observed, the loss in belts is about 5 per cent. of the power transmitted.

The rims of two pulleys connected by a belt move with approximately the same velocity ; therefore, their revolutions are approximately inversely proportional to their diameters. There is, however, a certain amount of slip, and hence the driven pulley rim actually revolves at a velocity about 2 per cent. less than that of the driving pulley rim. With a badly designed drive or if the belt speed is excessive, the slip may be much more. If a slip of over 30 per cent. occurs, the belt is apt to fly off. Excessive slip wears out belts quickly by abrasion and overheating.

9. **Arrangement of drive.**—When two shafts are parallel, the two pulleys of a drive must be in line. This can be roughly tested when they are being erected by stretching a string across the edges of the pulleys. A more accurate method is to sight along a straight-edge laid across the side of each pulley.

Where the shafts are to run in opposite directions the belt must be crossed, the pulleys being lined up as though for a straight drive, Pl. **122**, Fig. 9. Crossed drives will transmit more power than straight ones owing to the larger arc of contact, but cause rapid wear of belts.

Where the drive is angular, the shafts not being parallel, the pulleys must be so placed that the belt runs on to each in a line with the centre plane of the pulley, as shown on Pl. **122**, Fig. 10. The belt may be running off the pulley at an angle, but will nevertheless remain on the pulleys and transmit power satisfactorily if led on straight.

Where, owing to obstructions, it is impossible to stretch a belt directly between pulleys placed on two shafts, jockey pulleys may be used to change the direction of motion of the belt as desired, as shown on Pl. **122**, Fig. 11. A jockey pulley should be as large as the smaller pulley of a drive, well balanced, and very rigidly held but adjustable in position, so

that the belt may be tightened or adjusted to run accurately on to either pulley by moving the jockey.

Belts should always be ordered in widths of whole numbers of inches, since standardization reduces cost. It is generally preferable to use thin wide belts rather than thick narrow ones, because thin ones last better and waste less power in friction.

The length of belt required for a straight drive is approximately twice the distance between pulley centres plus half the circumference of each pulley. To this must be added enough for the joint.

10. **Pulleys.**—*Material and design.*—Pulleys for belts are usually of cast-iron in small sizes, but large sizes may be built up of steel, with cast-iron hub bosses, to save weight. Built-up wooden pulleys are sometimes used.

Where it would be inconvenient to remove shafting from its bearings in order to slip a pulley along it, split pulleys should be employed, which can be placed round the shaft anywhere, and the halves bolted together, as shown on Pl. **123**, Fig. 1.

Large split pulleys should always be built up, since steel is better able to withstand the centrifugal stress, and in large sizes built-up pulleys are generally cheaper. The arms of steel pulleys may be cast into the boss or may be screwed in. They are normally riveted to the rim, which is countersunk to produce a smooth surface, Pl. **123**, Fig. 2. Wide pulleys should have two rows of arms.

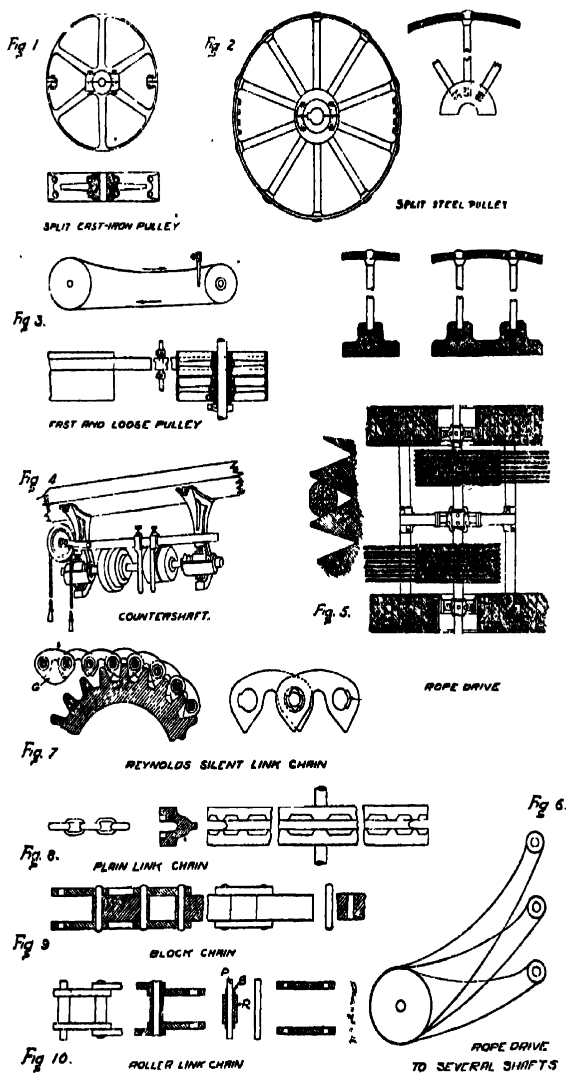
The rims of pulleys should normally be crowned about $\frac{1}{8}$ inch per foot width. A belt always tends to run centrally on a crowned pulley without guides of any kind, but more crowning than this defeats its object by decreasing the area of contact between belt and pulley. The rim of a pulley should be at least half an inch wider than the belt.

Since standardization considerably reduces cost, pulleys should always be ordered to whole numbers of inches, both in width and diameter. The size of shaft, and type of keyway, if desired, must also be specified. Split pulleys for light loads grip sufficiently without any key. For heavy loads a plain feather key as long as the pulley boss should be used. Taper keys should not be used.

11. **Fast and loose pulleys.**—Pulleys for a fast and loose drive may have flat rims, since guides must be provided for the belt, Pl. **123**, Fig. 3. The driving pulley must be twice as wide as the belt plus one inch, and must be quite flat. The driven pulleys are the normal width, one being keyed to the shaft and the other free to revolve, but kept in place by a collar. Loose pulleys are normally bushed with bronze or

PLATE 123.

ROPE AND CHAIN TRANSMISSION



run on ball bearings, since it is difficult to ensure sufficient bearing area or lubrication for a cast-iron bearing. Lubrication is best provided by fitting a Stauffer or Reisert grease cap. *See* Sec. **157**, para. 5. Striking gear must be fitted to shift that part of the belt which is running on to a pulley. The forks should be long and of large diameter. They should act on the driving side of the belt.

The forks of striking gear for heavy belts, especially link belts, should carry rollers, preferably not less than three inches in diameter and twelve inches long, free to revolve. Friction, damage to belt, and noise in running are thereby reduced to a minimum.

Note that the fast and loose pulleys must be on the driven shaft as it is not possible to *strike* a stationary belt.

12. **Countershafts.**—Where the ratio of speeds between the line of shafting and the pulley shaft of a machine is more than six, an intermediate shaft or countershaft must be used, running at a speed approximately midway between them.

In other cases it is often convenient to provide a countershaft, either to diminish the length of drive or to keep belts out of the way of operators.

Where stepped pulleys are necessary and a fast and loose drive is also required, a countershaft must be provided, unless a clutch is used in place of the fast and loose pulleys, fitted to one of the stepped pulleys.

For purposes of standardization, the shafting, pulleys, and bearings of a countershaft should be similar in size and design to those of the main shaft-line. On the other hand, plain plummer blocks and lighter shafting, if already in stock, can be used with success, since the shaft is usually very short and carries little load.

Pl. **123**, Fig. 4, shows a typical countershaft for a lathe with swivelling bearings, cone pulleys, and fast and loose drive.

13. **Rope drives.**—Ropes are used for the transmission of power in larger quantities than can be satisfactorily dealt with by flat belts. They are run in grooved pulleys, of diameter not less than thirty times the diameter of the rope, Pl. **123**, Fig. 5. Grooves should be plain V in shape, deep enough to ensure that the rope will never touch the bottom when worn, the sides making an apex angle of 40°. It is advantageous for the width of the grooves at the top to be at least $1\frac{1}{2}$ times the diameter of the rope. Larger ropes can then be substituted if more power is required later on.

Ropes are twisted leather, hemp, or cotton, well greased with tallow and graphite. Cotton is much the most satisfactory. The tension in a good cotton rope may be $200d^2$ lbs., where d = dia. of rope in inches. Ropes are normally run at

high speeds, and work satisfactorily up to 7,000 feet per minute. At 5,000 feet per minute, a normal working speed, each 1-in. diameter rope will transmit 16 horse-power.

A cotton rope drive is specially suited for drives in which one large engine supplies power to several shafts, Pl. **123**, Fig. 6, as in textile factories, and also for positions in which the rules for flat belts cannot be observed. The length of drive may be as short as desired or may be up to 100 feet; vertical drives run satisfactorily. The drive is silent and free from vibration. Ropes will last ten years with reasonable care, and require less attention than belts.

Ropes should be joined with a splice 10 feet long, the diameter of the rope being maintained as uniform as possible by gradually reducing the thickness of the strands. The rope should be specially woven, with strands having a core of parallel threads surrounded by protecting twisted threads, Pl. **123**, Fig. 5. The splicing, therefore, needs great care and skill.

14. **Chain drives.**—*Principle.*—Where a large amount of power must be transmitted at a medium speed, chain drives provide a reliable and positive method of transmission. The chain is run on sprockets, which are pulleys with projections on their rims which engage the links and so prevent slipping.

Silent chain drives.—The best type is that known as silent chain.

Each link consists of several plates, carrying projections which engage with flat-sided teeth on a broad sprocket, as shown on Pl. **123**, Fig. 7. There is practically no friction except that between the links and their pins.

This is the most suitable type for shop transmissions, since it is reasonably silent and needs less lubrication than other types—a great advantage in textile mills, where oil must not drip or splash about.

It is made in standard sizes up to 25 tons working tensile strength by several makers, who claim an efficiency of 98 per cent. at 1,200 feet per minute.

Drives may be very short, and the ratio is only limited by the minimum number of teeth that will provide smooth running on the smaller sprocket. With silent chain the limit is about ten to one, the smaller sprocket having not less than eight teeth.

The outer plates of silent chain are usually guide plates, G, to keep the chain on the sprocket by enclosing the teeth. They add to the tensile strength of the chain, but do not bear on the teeth at all.

The pins and pin bushings, B, are usually made of very hard steel to prolong the life of the chain. Some patented types of chain have knife-edge rocking pins for the same purpose.

Jockey pulleys for silent chain should be toothed sprockets engaging the working face of the chain. If plain pulleys are used upon the back of the chain, the links rapidly wear and burr, and this ruins the chain.

The ratio of velocities of driving and driven sprockets is inversely proportional to the number of teeth they contain. Although positive, the drive is more elastic than that of toothed gears. This elasticity has been further increased by some makers by introducing springs into some or all of the links.

Lubrication.—The effective lubrication of chains is difficult. When they cannot be run in a bath of oil or with a continuous drip, a thick lubricant must be used, since a thin oil is quickly shed by centrifugal force.

The chain should be immersed in a large quantity of solid lubricant, such as a mixture of heavy mineral grease and deflocculated graphite, at a high temperature, kept in it for some hours, and moved about to facilitate entrance into the link joints. The lubricant should then be allowed to cool. The chain should then be taken out and wiped clean.

On no account should a greased chain be *oiled* with ordinary machine oil. Not only would this produce no lubricating effect, but the chain would then appear oily, and would, therefore, be liable to be passed over when next due for greasing; moreover, it would splash oil about when running.

Wear.—All chains wear at the pins, and so become longer as the pins decrease in diameter and the holes wear oval. In consequence, they tend to ride higher upon the teeth.

This is not a great disadvantage, but finally the chain rides high enough to slip over the top of the teeth. Both the chain and sprockets must then be renewed.

The distance between sprockets should be adjustable, because chains are always lengthening as they wear. Alternatively, a jockey pulley may be provided, so that the chain can be kept reasonably tight, or links may be removed from time to time.

Other types of chain.—There are other types of chain, for example :—

Plain link chain, running in V-grooved wheels with moulded sides to the grooves to grip the links, Pl. **123**, Fig. 8. This type is only used in such appliances as differential tackles, where great efficiency is not required, noise can be permitted, and which are only used occasionally. Its only advantage is that of cheapness.

Block chain, consisting of a series of short blocks, alternating with pairs of strap links, and held together with steel pins, as shown on Pl. **123**, Fig. 9. It is heavy; there is friction between the blocks and the teeth of the sprockets, which enter between the straps, resulting in noise, wear, and

considerable frictional loss. Its use is almost confined to conveyors.

Roller link chain, Pl. **123**, Fig. 10, every link of which consists of a pair of straps. The pins, P, work in bushes, B, which carry rollers, R, to diminish the friction and wear on the pins. The sprockets carry a tooth for each pin. The running is smoother than with block chain, and the sprockets can be smaller for the same load.

This is the normal type used in cycles and in some motor vehicles.

152. *Toothed gears*

1. **Classification.**—Gears, or toothed wheels, are said to be *spur gears* when the teeth are cut parallel to the axle or shaft and the two shafts are parallel, as shown on Pl. **124**, Fig. 6.

Bevel gears are conical, and are used when the two shafts are at an angle and their centre lines meet at a point. This point is also the apex of both cones, of which the gear blanks are portions, Pl. **124**, Fig. 1.

Where they are used, a considerable longitudinal thrust is caused in the shafts, which necessitates thrust bearings and causes a loss in efficiency due to friction.

Mitre gears are equal-sized bevel gears for shafts at right angles.

Skew gears are used between two shafts which are not parallel, but cross one another so that their centre lines do not meet. Skew gears are rarely used. They are expensive to make and seldom necessary. The term is frequently, but incorrectly, applied to *screw gears*.

Screw and worm gears.—The shafts are at right angles and not in the same plane. A common example is the *screw* gear for working the cam shaft of an oil engine. They are, however, quite different from skew gears, in that the power is transmitted by the screwing action of helical teeth and not by direct thrust of one tooth on another.

2. **Spur gears.**—Plain spur gears are generally of cast-iron. For expensive machinery in which loads are heavy they may be of steel, or steel and bronze alternately.

For cheap slow-running machinery, the teeth can be cast and hand-cleaned with a file.

For fast-running machinery and any which must run quietly and smoothly, the teeth must be very accurately cut from solid blanks. They are cut either to a cycloidal curve or to an involute, either of which gives a fairly smooth rolling motion between the teeth with very little friction.

Sliding friction cannot be entirely eliminated by any form of tooth. A more important feature of correctly formed

teeth is that the velocity ratio of the two gear wheels shall remain constant. With teeth of incorrect form, if the speed of the driving wheel is steady, the speed of the driven wheel will vary slightly while each pair of teeth travel through their arc of contact, resulting in considerable vibration, noise, and wear.

Cycloidal teeth are little used except for delicate instruments ; they probably give the best results, but are expensive to make, and have practical disadvantages ; a pair of wheels must be designed to suit one another, and will not gear correctly with another wheel of a different size ; and they must be accurately adjusted at the correct distance apart.

Involute gears are almost universally used. Any involute gear wheel will run correctly with any other of the same pitch and obliquity [*see below*], and slight errors in separation of the wheels are unimportant. Moreover, they can be easily and accurately generated by milling, grinding, or planing ; for while the teeth on a wheel are convex faced, the convexity decreases as the radius of the wheel increases (the size of the teeth remaining unaltered), until in the limiting case of a wheel of infinite radius, *i.e.* a straight rack, the teeth are straight sided. The angle which the faces of the teeth make with the perpendicular to the rack is called the *obliquity* of the teeth. This rack can be machined with great accuracy, and a planing tool can be ground to the profile of the teeth. *See* Pl. **125**, Fig. 1.

As the rack will gear correctly with any wheel of the same pitch and obliquity, the tool so formed can be used to cut the teeth on a wheel of any size, if the wheel be rotated, and the tool traversed at the correct speed. This can be done in a special machine, the gear planer.

Pl. **125**, Fig. 2, shows how the teeth can be formed by grinding with a grinding wheel, with a straight cutting side working at an angle to the radius of the gear-wheel.

By this method a cutter in the form of an involute gear-wheel, with the cutting edges on one face of the wheel, may be formed ; this cutter may be used for cutting wheels with any number of teeth ; the cutter moves axially to take the cut, and at the same time cutter and gear-wheel are rotated very slowly at the correct relative speeds. (Pl. **125**, Fig. 3.)

3. **Helical gears.**—In very high-speed machinery, such as the reduction gear of turbines, helical gears, as shown on Pl. **124**, Fig. 2, are used. In these, the teeth are cut at an angle across the face of the wheel blank, so that contact between two teeth takes place first on one side, and gradually passes across to the other as the gears turn. By this means shock and noise is almost entirely eliminated, but a longitudinal thrust on the shaft is produced. Two such gears

PLATE 124.

GEARS AND GEARING.

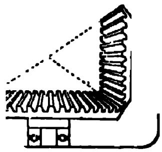


Fig 1 BEVEL GEARS

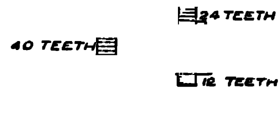


Fig 6 TRAIN OF GEARS

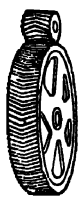


Fig 2 DOUBLE-HELICAL GEAR

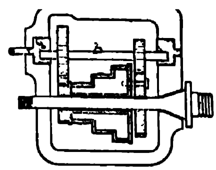


Fig 7 BACK GEAR OF LATHE

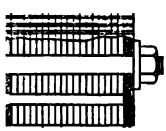


Fig 3. RAW-HIDE PINION

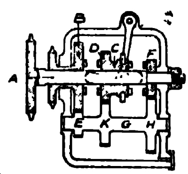


Fig. 8 TYPICAL MOTOR-CYCLE GEAR BOX THREE SPEEDS

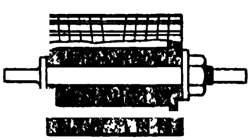


Fig. 4. FLEXIBLE PINION

Fig 5 INVOLUTE TEETH

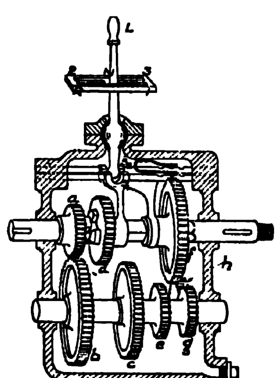


Fig 9. SELECTIVE GEAR BOX 3 SPEEDS AND REVERSE

PLATE 125.

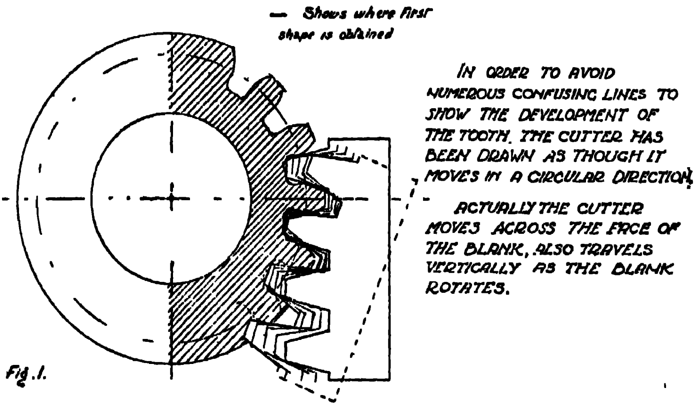


Fig. 1.

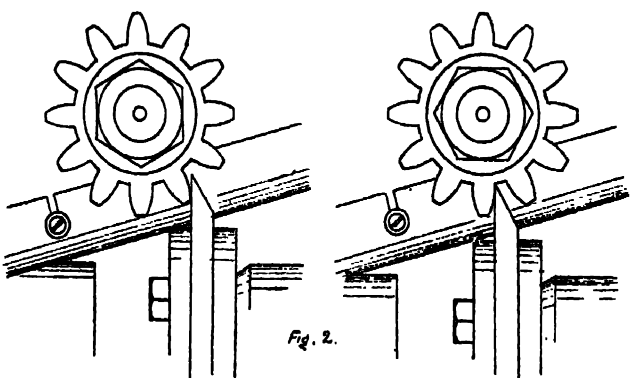


Fig. 2.

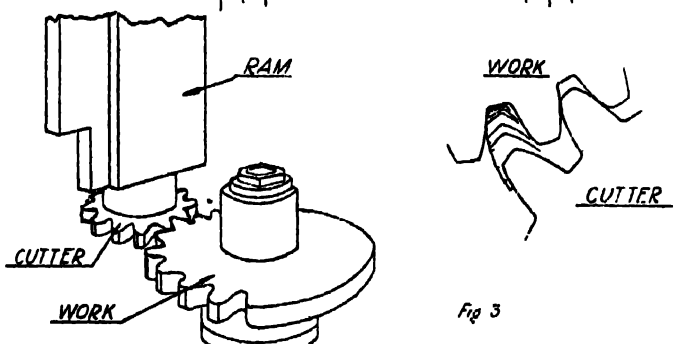


Fig 3

placed side by side, having teeth inclined in opposite directions as shown, cause opposite thrusts which balance one another. Such gears are called *double-helical.*

The pinions are usually of nickel steel and the larger wheels of carbon steel of about 35 tons/sq. in. tensile strength.

The efficiency of transmission through well-cut double-helical gears is very high, approximately 98 per cent.

4. **Silent gears.**—All metal gears with parallel teeth, *e.g.* spur gears, are inclined to be noisy, especially if they run fast. To reduce the noise, it is usual to make a fast-running pinion of raw hide or some special compound, of which there are several on the market, such as *Fabroil.* The pinion blank is made by compressing discs of raw hide or other material between two discs of steel by some such arrangement as that shown on Pl. **124,** Fig. 3, and then the teeth are cut as though the blank were solid metal.

Such gears run well under a comparatively light load at very high tooth velocities, and almost silently.

Oil is very harmful to raw hide, and must not be allowed to get on to such pinions. They should be lubricated with a mixture of graphite and tallow.

For tooth pressures that are too high for raw hide, pinions are similarly made by building them up of plates of spring steel. These plates are not necessarily flat. A considerable increase in flexibility is obtained by coning them at various angles, as shown on Pl. **124,** Fig. 4.

5. **Speed ratios.**—In the case of all gears, whether spur, bevel, or skew, two gears working together must turn at speeds exactly in inverse proportion to the number of teeth they contain. Thus two gears of 48 and 12 teeth must revolve at a speed ratio of 12 to 48, or 1 to 4, the smaller gear moving at the higher speed. The smaller of two gears whose ratio is large is generally called a pinion.

The possible ratio is only limited by the necessary number of teeth on the pinion for smooth working. No pinion should have less than 12 teeth normally, or 8 if specially designed. Gears can be made up to any size that existing machinery can deal with, so that the ratio is theoretically unlimited.

In practice, a ratio of six to one is seldom exceeded, except in turbine reduction gears, in which, by the use of double-helical gears of fine pitch and great width and made of alloy steels of great strength, a ratio of ten or more to one can be used, but the number of teeth in a double-helical pinion should not be less than 22.

6. **Pitch.**—Two gears working together, as shown on Pl. **124,** Fig. 5, and having a ratio of two to one, if placed with their centres at 6 inches distance, revolve at the same relative

speed as two smooth friction pulleys of 4 and 8 inches diameter respectively, whether the teeth are large or small. The *pitch diameters* are said to be 4 inches and 8 inches respectively. The two circles 4 inches and 8 inches diameter representing these theoretical friction pulleys are called the *pitch circles* of the gears.

The distance measured along a pitch circle between the centres of two teeth is the *circular pitch* of the teeth.

A gear is usually described and ordered in Great Britain by stating the *diametral pitch*, which is a conventional term for the number of teeth it has for every inch diameter of its pitch circle. Thus a *ten pitch* gear of 4 inches pitch diameter has 40 teeth. Since the circumference of its pitch circle is 12·57 inches, the circular pitch of the teeth is $\frac{12{\cdot}57}{40}$, or 0·314 inch. The clearance below the pitch circle is usually made more than the projection of the teeth beyond it by 8 per cent. of the total depth of the teeth. It is important that the teeth should be properly engaged. If there is much less than 8 per cent. space between the ends of the teeth and the bottom of the clearance the teeth tend to jam. If there is much more, the teeth will be weak and liable to strip off.

7. **Gear trains.**—*Compound ratios.*—When the ratio of speeds required cannot be obtained by a single pair of gears, a train of gears is used, as shown on Pl. **124**, Fig. 6. The total ratio is the product of the ratio of each pair. Thus the numbers of teeth being 10 and 40 for the first pair, and 12 and 24 for the second pair, the total reduction in speed is $\frac{40}{10} \times \frac{24}{12}$, or 8.

Fractional ratios.—In practice, even ratios are not used for machinery which is to run continuously, because a tooth on one gear would then be always engaging the same tooth on the other, and any unevenness in manufacture or in hardness would be apt to produce more wear in one tooth than another, and, in consequence, a rhythm or vibration.

By using odd numbers and fractional ratios, it can be ensured that each tooth on one gear engages every one on the other in turn, and so all wear evenly. Thus, in the example given above, if the denominators are exchanged the same reduction will be obtained with less vibration, since $\frac{40}{12} \times \frac{24}{10}$ is also 8.

A still smoother effect would be obtained by using the ratios $\frac{36}{11} \times \frac{22}{9}$, which also give a reduction of 8 with no possibility of any rhythm.

Chasing teeth.—Where the exact ratio is unimportant, rhythmic vibration can be eliminated most simply by adding one tooth to the larger gear, known as a *hunting tooth.* Thus, for a crane requiring a reduction of 4, $\frac{41}{10}$ is sufficiently accurate and ensures uniform wear.

Back gears.—In gears such as the back gear of a lathe, Pl. **124,** Fig. **7,** where a lay shaft, *b,* is used to produce a reduction in speed between the two pulleys and the spindle, the sum of the diameters of one pair of gears must be the same as that of the other pair.

If the same pitch of teeth is to be used, the sum of the numbers of teeth on one pair must be equal to that of the other. The reduction is then most simply obtained by making the ratio of each pair the square root of the total required, if possible. Thus a reduction of 9 to 1 can be obtained by $\frac{3}{1} \times \frac{3}{1}$.

8. **Gear boxes.**—*Purpose.*—The drive of mechanical vehicles, and also some machines such as the more complicated lathes and milling machines, require various speed ratios to be available, and it must be possible to change the ratio without delay. This is usually made possible by means of sliding gears.

Progressive gears.—Pl. **124,** Fig. 8, illustrates a three-speed gear box for a motor-cycle. The shaft, A, driven by the engine, carries upon it (*a*) the driving sleeve, B, which is free to revolve upon it, (*b*) the sliding sleeve, C, which is squared inside to fit over a square on the shaft and carries a gear, D, and (*c*) the pinion, F, which can revolve freely.

The driving sleeve, B, carries a gear keyed to it. There are dogs on the face of B and F, and on both faces of C. The sliding sleeve, C, can be moved by means of a lever and jaws working in a groove, so that C can be coupled with B or with F, or it can occupy any intermediate position on the shaft, neither of the dog clutches being in action.

The lay shaft, G, carries three keyed gears, of which E is always in mesh with B, H with F, while the centre gear K engages D on the sliding sleeve when it is in the centre of its travel.

There are thus three separate ratios available :—

i. Extreme left position, direct-coupling through the dog clutch, lay shaft running idle.

ii. Centre position, D drives K, E drives B, ratio $\frac{K}{D} \times \frac{B}{E} = \frac{B}{E}$.

iii. Extreme right position, C coupled to F, F drives H, E drives B, ratio $\frac{H}{F} \times \frac{B}{E}$, which generally is nearly $\frac{B^2}{E^2}$.

Between (i) and (ii), and again between (ii) and (iii) there must be a position in which no gear is engaged, known as the neutral or *free engine* position.

The shafts are usually carried on ball bearings, and A generally contains a friction clutch, which is omitted in order to simplify the figure.

9. **Selective gears and gate changes.**—When motor vehicles are provided with more than three gears, a gate change is normally fitted, which ensures that only one gear can be engaged at a time. On Pl. **124**, Fig. 9, the lever, L, can be placed in the central position, or rocked to left or right sufficiently to engage the selector bars, S_1 and S_2. It can then be pushed forward or backward, carrying the selector bar with it and so engaging the gear required.

The other selector bar can only be engaged by bringing back the lever through the central or neutral position, and this movement disengages the gear which was in use before. The selector bar, S_1, controls the position of the sliding gear, *d*, which fits on a squared portion of the transmission shaft, and has dogs to engage those on *a* which is keyed to the clutch shaft.

i. When the lever is placed in position 3, S_1 is engaged and *d* engages *a*, giving direct coupling.

ii. When the lever is placed at 2, the same selector bar is still engaged, but *d* is moved so that its teeth engage those of the gear, *c*, on the lay shaft. The gear reduction is then $\frac{a}{b} \times \frac{c}{d}$. Generally $\frac{c}{d}$ is unity or nearly so.

iii. When the lever is placed at N, the selector bar, S_1, is automatically left in its middle position, which ensures that *d* is completely disengaged. A spring catch keeps S_1 in this position until moved by the lever.

iv. When the lever is moved to position 1, S_2 is engaged and carries its sliding gear, *f*, into mesh with *e* on the lay shaft, so that the gear reduction is $\frac{a}{b} \times \frac{e}{f}$.

v. In the position R the lever, still acting through S_2, carries *f* into mesh with the pinion, *h*, on a third or reverse shaft, which is always driven by *g* on the lay shaft. In consequence, the transmission shaft revolves backwards, with a gear reduction $\frac{a}{b} \times \frac{g}{f}$.

153. *Indirect transmission systems*

1. **General principle.**—Power may be indirectly transmitted by means of a pressure generator and motors, the methods available in ordinary practice being electrical, pneumatic, and hydraulic transmission.

2. **Electrical transmission.**—*Efficiencies.*—The transmission of power by electricity compares favourably, as regards efficiency, with mechanical methods when power is to be carried some distance and in large quantities. The capital outlay is heavy, being about double that for mechanical transmission, prime mover and transmission to machine included.

(*N.B.*—We are dealing here with the case of an isolated station. If a central electric supply system is available it would generally be used to avoid the installation of a prime mover. It should also be noted that the losses in electrical distribution vary with the load, whereas the losses in shafting are practically the same at all loads. *See* Textbook of Electrical Engineering, page 436.)

In transmitting small quantities of power the electrical losses are very large, since the efficiency of a small dynamo or motor is only 80 per cent., while 2 to 5 per cent. is lost in the conductors, so that the overall efficiency is about 60 per cent.

Convenience.—The great convenience of the absence of shafting, portability, cleanliness, and complete switching-off of power consumption when machines are not in use, renders electrical transmission ideal for workshops in the field.

Application to shop drives.—In stationary workshops in peace time the economic limit below which it is not normally advisable to instal a motor is 5 horse-power. The size of motors, and, therefore, their efficiency, can be increased by grouping machines, and driving short lengths of shafting by motors of 5 to 10 brake horse-power. By this method an overall efficiency of transmission of 70 per cent. may be obtained in favourable circumstances.

Portable tools.—Where electrical power is already available, it provides a convenient and silent method of driving portable drills and grinders. The efficiency of such small motors is very low, but compares favourably with that of pneumatic transmission.

Electric motors of less than 3 horse-power should, however, be avoided, except where rapidity of installation is paramount, as the efficiency falls very rapidly with further reduction in size, while the first cost only falls approximately as the square root of the power.

3. **Pneumatic transmission.**—*Efficiency.*—The transmission of power by compressed air is always expensive and inefficient, partly on account of the large loss of energy due to the necessity of cooling the compressed air, and also on account of the frictional resistance in the pipes.

As a method of transmission it cannot compete with other methods in efficiency, but a supply of compressed air is essential in a works of any size.

Application.—The work to which it is normally applied includes riveting and chipping of all kinds, including boiler scaling, and drilling, reamering, and tapping holes.

It is very convenient for boiler and other riveting and plate work, since the tools are light and easily handled. It is particularly adapted to pressure tools.

4. **Hydraulic transmission.**—*Efficiency.*—The transmission of power by means of water supplied through pipes at very high pressures is not only very convenient, but provides a highly efficient form of reduction gear of very large ratio, provided it is only used for giving very slow motions and the velocity of the water in the pipes is kept low.

Presses and lifts.—For forging, flanging plates, and riveting, it is the most efficient and silent method known. With the slow movement of a plunger multiplied by means of a jigger or multiplying tackle, it can be applied to lifts and cranes with fair efficiency.

Motors.—Motors of the short-stroke, single-acting, reciprocating type are also used. While enormously powerful for their size, they are of low efficiency, owing to wire-drawing in passages and valves and the inertia of the water. They should only be used for very slow powerful work, or for occasional impulses, as for turntables and for capstans used for moving trucks in goods yards.

Hydraulic transmission is also used as a reduction gear for turbines, the steam turbine driving a centrifugal pump, which circulates water through a water turbine direct-coupled to a generator or to the propeller shaft of a ship. An efficiency of 90 per cent. is sometimes attained.

154. *Practical application*

1. **Shaft drive calculations.**—The following is an example of the application of the data given in Secs. **147** to **151** to the lay-out of a small workshop. It is assumed that :—

i. Machines are to be installed aggregating 50 B.H.P. which are estimated to require a total at any one time of 20 horse-power at the machine pulleys, and that on the average each machine has one countershaft. One or two may have no countershaft, while one or two may need two to give the necessary spindle speed.

ii. An engine is available that may be relied upon to produce the necessary power, and that its pulley is 3 feet in diameter, of ample width, and revolves at 200 revolutions per minute.

iii. The workshop building has been designed for the purpose, with cross girders at a height of 11 feet clear above the floor to which hangers can be fixed to carry shafting at intervals of 10 feet, and that all the machines can be grouped so that their countershafts can be driven from one line of shafting 100 feet long.

2. **Size of engine required.**—Calculations for the friction, &c., losses in main shafting, belts and countershafts are seldom worth while. It may be assumed, however, that with a bush-bearing installation in good condition the horse-power lost in the transmission will be about half the maximum demand. In our example this will be 10 H.P., therefore the engine should be capable of developing 30 B.H.P.

3. **Belt sizes.**—The belt from the engine to the mainshaft must transmit 30 H.P. at a rim velocity of $3\pi \times 200$ feet per minute. The effective pull in the belt $(T - t)$, *see* Sec. **151**, para. 3, must be $\frac{30 \times 33{,}000}{3\pi \times 200}$ lbs. $=$ 525 lb.

The choice lies between :—

i. Single leather, 45 lb. per inch wide, *i.e.* a 12-inch belt.

ii. Double leather, 75 lb. per inch wide, *i.e.* a 7-inch belt.

iii. Canvas, &c., precise width from the maker's tables, but it will not differ much from leather of the same thickness.

iv. Link belt, 88 lb. per inch section, *i.e.* 6 square inches of 8 inches $\times$ $\frac{5}{8}$ inch belt would be suitable. There is little reason for using link belt, since the pulleys are large. If fast and loose pulleys are to be placed on the shaft, link belt would be noisy and would not wear well.

A single leather belt would be somewhat too wide. The choice is thus limited to double leather or canvas, of which the latter would be the cheaper.

Each belt in turn driving from the mainshaft to the countershaft, and thence to a machine, must be separately calculated in the same way. In the case of those running from mainshafts to countershafts, it may be necessary first to decide upon the diameter of the pulleys to be used.

4. **Mainshaft line.**—

i. The speed of the mainshaft should be moderately high, since all gear can be thereby lightened. If a pulley of 2 feet 6 inches diameter is driven from the 3-foot engine pulley running at 200 r.p.m., the shaft speed will be about $\frac{36}{30} \times 200 \times \frac{98}{100} =$ 236 r.p.m.

ii. There will probably be no difficulty in passing the driven pulley on to the end of the shaft while it is being erected. A solid cast-iron pulley may therefore be used if desired.

Fast and loose pulleys are advisable, so that the engine may be started up light. These pulleys should be placed close up to a bearing if possible; otherwise their weight and the pull of the belt will produce heavy bending stresses in the shaft. An extra bearing, close to the other side of the pulleys, would minimize these stresses, and should be provided if the structural arrangements permit.

iii. The distance between the centres of bearings is fixed at 10 feet by the spacing of the joists. The diameter of shafting used must, therefore, be approximately such that $60\sqrt[3]{D^2} = 120$. From this it appears that $2\frac{3}{4}$-inch shafting is the smallest which would be satisfactory. 3-inch would be a better standard.

To transmit 30 H.P., the shaft diameter must comply with the formula :—

$D = 3{\cdot}75\sqrt[3]{\frac{H.P.}{N}}$ (*see* Sec. **148**, para. 1), *i.e.* D must not be less than 1·93 inches.

From this it appears that 2-inch shafting would have been strong enough if the structure had admitted a closer spacing of the bearings, such as 8 feet intervals.

iv. The length of the actual bearing surfaces in which the shaft runs should be not less than $3 \times 2\frac{3}{4}$, or 8 inches. The outside length of the shell will be 10 or 11 inches.

v. The hangers should be selected with a view to avoiding any difficulties in fitting pulleys of large sizes if required at the time or at any later occasion; *e.g.* pulleys up to 4 feet diameter may be required, and they must not be less than 7 feet clear from the floor, while clearing all roof structure with ample

margin. The shafting should, therefore, be carried somewhat less than 2 feet below the cross joists and well clear of all obstructions.

The position of belts from mainshafts to countershafts must also be considered. To make these clear all roof structure it may be necessary to use hangers of the full 2 feet drop. Whenever possible, however, it is better to avoid the use of hangers and provide bearings on the tops of the cross-girders.

5. **Alternative electric drive.**—If electrical power is available, the convenience of the shop may perhaps be improved by grouping the machinery so as to be driven by two shafts, each providing about 12 horse-power and each driven by its own separate motor.

CHAPTER XXXIII

LUBRICATION

155. *Principles of lubrication*

1. General principles.—The principle of lubrication is the elimination of solid friction between moving surfaces by the substitution of fluid friction, which is very much less in amount and does not involve wear and damage to the working parts.

The most perfectly ground surfaces are rough when viewed under the microscope, and the coefficient of friction between bare metals is very high, causing tearing away and destruction of the surfaces if a bearing is allowed to run dry.

If a film of liquid can be maintained between the surfaces, the only friction is the internal friction of the liquid, which tends to adhere to the surfaces.

The film is, however, gradually squeezed out under pressure. The fluid must therefore possess sufficient viscosity to resist squeezing out long enough to enable the film to be renewed before it breaks down.

Viscosity is, however, not a measure of the lubricating power of the liquid; on the contrary, high viscosity implies high fluid friction and consequently less effective lubrication. The lubricating power of any liquid depends chiefly on the somewhat indeterminate but easily recognisable property which may be termed "Oiliness." Exactly what constitutes oiliness is not easy to say, but it appears to be a surface-tension effect which resists the final break-down of the film, without affecting the ease with which the particles of the liquid slide past one another.

Thus we can easily recognize that a fluid such as treacle, though viscous and not easily squeezed aside, nevertheless does not maintain a film between the surfaces when squeezed between finger and thumb, while quite a light and liquid oil cannot be squeezed out altogether except by considerable pressure.

Unless oil is forced into a bearing under pressure, lubrication is only possible if :—

i. There is a portion of one surface which is free from pressure.
ii. Oil is continually spread there.
iii. The oiled portion sweeps the whole of the other surface, so as to cover the latter with an oil film.
iv. It returns to be oiled again before the pressure has squeezed out the oil film.

In such a bearing, perfectly lubricated, there is no metallic friction, but merely a resistance to movement due to the viscosity or stiffness of the oil. Therefore, in an ordinary bearing, oil should be led in on whatever side has normally no pressure; for instance, the top of line-shaft bearings, and the top of a wheel hub revolving on a fixed axle, but the bottom of a railway axle-box.

In thrust bearings, where there is no *side free from pressure,* it is necessary to provide one artificially, by cutting away a sector of one of the surfaces, as described for Michell thrust bearings in Sec. **149**, para. 9.

A thin oil may be used in rapidly-revolving bearings, whereas in slowly-moving ones, such as a country-cart wheel, only a thick grease can withstand the load for the long period between one revolution and the next one.

156. *Properties of lubricating oils*

Lubricating oils vary widely in their qualities, and to obtain good results it is essential to exercise care in the selection of an oil to suit particular circumstances.

The principal factors affecting the quality are as follows :—

1. Specific gravity.
2. Viscosity.
3. Oiliness.
4. Flash-point.
5. Pour-point.
6. Evaporation and gumming.
7. Asphalt content.
8. Acidity.
9. Emulsification.

1. **Specific gravity.**—This can be measured with sufficient accuracy by a hydrometer. It is no criterion of the lubricating value of an oil, but it is an indication of its origin. The paraffin base oils (S.G. 0·88–0·91) have a smaller ash content than the asphaltic base oils (S.G. above 0·91) and are, in general, better lubricants.

2. **Viscosity.**—This is a measure of the *internal friction,* or, in common terms, *thickness* or *body* of an oil. When an oil is said to be *light* or *heavy*, it is the viscosity which is referred to and not the specific gravity. There is no relationship at all between viscosity and specific gravity.

The true definition of viscosity is :—

"The viscosity of a fluid is measured by the tangential force on unit area of either of two horizontal planes at unit distance apart, one of which is fixed, while the other moves with unit velocity, the space between the surfaces being filled

with the viscous substance. Increase of pressure between the surfaces is accompanied by a rise in viscosity, and over the range of bearing pressures used in practice the value may be anything up to 20 times the value at atmospheric pressure."

This is the correct way of looking at the matter, and whereas viscosity in some degree is necessary for all lubricants, a high viscosity is only necessary for heavily-loaded slow-moving bearings. In fast-moving machinery the heavy drag resulting from the use of a thick lubricant would cause a large loss of power in bearings, while a comparatively light oil of low viscosity is capable of supporting the load for the short period between revolutions, and causes far less drag.

The viscosity of oils is diminished if they are heated. In testing an oil for any definite purpose, it is essential that the test shall be carried out at the temperature at which the oil may be expected to be when the machinery is running. For instance, ordinary shaft bearings normally run at from 100° to 120° F. in summer, and may be as cool as 60° to 70° F. in winter, while the bearings in an enclosed engine crankcase may run up to 200° F.

For practical purposes the viscosity is expressed as the number of *seconds* taken for 50 c.c. to flow through the standard jet in the *Redwood* viscometer (shown roughly in Pl. **126**, Fig. 1). If the time taken were 120 seconds at 70° F., the viscosity would be stated as " 120 Redwood 70° F." There are other ways of expressing the viscosity, but this is the generally accepted method in Great Britain. The British standard *Nominal Viscosity* is the value at 140° F. Paraffin base oils do not fall so rapidly in viscosity with increase of temperature as asphaltic and naphthenic base oils.

In the absence of any special apparatus, a comparative test of any two or more oils may be made by placing a drop of each near the top of a sloping plate of glass, kept at the required temperature in a cupboard away from draughts or dust, and noting progress of the drops towards the bottom. The times taken to traverse a given distance, such as 1 inch or 6 inches, varying for convenience according to the type of oil, are fairly reliable indications of relative viscosity. *See* Pl. **126**, Fig. 2.

It must be clearly understood that good viscosity alone is no indication of the quality of an oil, but merely of its thickness ; just as water can be thickened by adding starch or gum to produce any desired viscosity up to semi-solidity, so a thin oil can be adulterated by the addition of gums or soaps to give it a fictitious thickness. Such adulteration is generally obvious, since colour is affected. A pure oil should be absolutely transparent. Heavy oils usually have a deep red colour, the depth of which, in the case of mineral oils, is often used as a visual test of their lubricating qualities.

3. **Oiliness** (the property of molecular adhesion).—The type of lubrication in which a complete film of lubricant is interposed between the rubbing surfaces, is known as "*perfect lubrication.*" There can exist, however, in certain cases, a type of lubrication in which the oil film is squeezed out, but separation of the surfaces is ensured by a layer of lubricant only one molecule thick. This is known as *imperfect or boundary lubrication.* Some oils more than others have the peculiar property known as "*oiliness,*" of forming such monomolecular layers, and the importance of this property as a safeguard in economic lubrication is considerable. This property depends upon the chemical constitution of the oil and is as yet imperfectly understood.

It has been suggested that there may be chemical union between the metal surfaces and the lubricant, with the result that within the space of a few molecular diameters there is in succession molecules of metal, metal oleate, oil, metal oleate and metal. In some cases the intermediate molecular layer of oil may be absent, and then the contact must be between metal oleate and metal oleate.

Whatever the explanation may be, there is no doubt that under heavy loads and low speeds "*oiliness*" is the most important factor in lubrication.

It is determined by measuring the coefficient of friction in a mechanical testing machine, which comprises a model bearing so heavily loaded as to produce boundary lubrication conditions.

It has been known for many years that certain animal and vegetable oils possess this quality of oiliness to a greater degree than most mineral oils. These animal and vegetable oils also have excellent viscosities, but, unfortunately, animal oils have a strong tendency to become rancid or acid and to attack metals, and vegetable oil to gum and so prevent the entry of fresh oil in a lubricating system. A mixture of mineral oil with a good animal or vegetable oil is frequently used for bearings with heavy loads and low speeds when the working temperatures are low. Such *compound* oils have better keeping qualities than the animal or vegetable oils alone. Recent experiments, however, appear to indicate the possibility of preparing pure mineral oil with sufficient "oiliness" to suit all purposes without dilution.

4. **Flash-point.**—At normal temperatures there must be no tendency to form explosive mixtures of oil vapour and air, and the rate of evaporation should be as slow as possible. To ensure this, the *flash-point* must be well above the working temperature.

The specified flash-point of an oil is that obtained by the "*closed test*" in the *Pensky-Martin* apparatus, shown roughly

in Pl. **126**, Fig. 3, in which the oil is enclosed in a small cylindrical vessel so that the vapour is not liable to be affected by currents of air.

The "open" flash-point can be roughly determined by heating the oil in an open cup, observing the temperature, whilst a small flame is periodically brought to the surface (without touching) of the oil. When a flash occurs a small bluish flame will pass over the whole surface of the oil, and the temperature is noted. Values obtained in this way are always considerably higher than those obtained by using the standard flash-point apparatus.

If the heating is continued above the open flash-point, a temperature will be reached at which the oil continues to burn, and this temperature is defined as the "*firing-point.*"

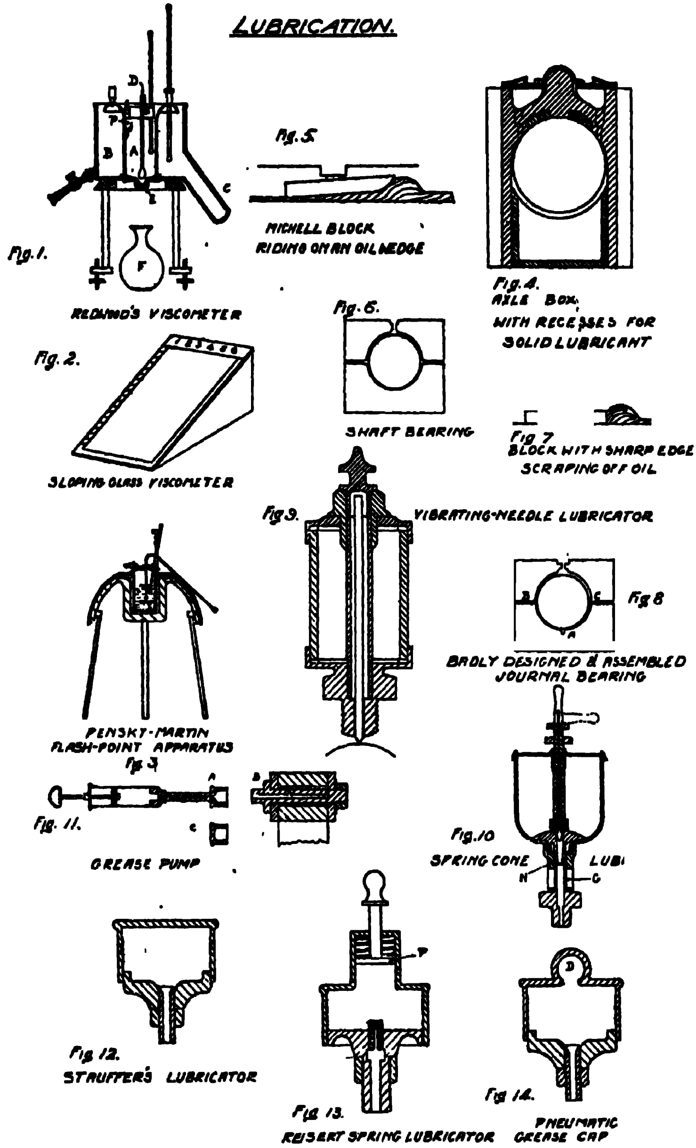
5. **Pour-point** (cold test).—The pour-point of an oil is taken as the lowest temperature at which it will pour, when it is chilled, without disturbance. As the temperature is reduced most of the animal and vegetable oils deposit solid fats and waxes. Some of the mineral oils also solidify into waxes, and in the case of Russian oil, although no definite solids are deposited, the oil becomes more and more viscous and forms a soft jelly which will not flow. The temperature at which this solidification occurs can be controlled to some extent in the refinery. To determine the pour-point accurately special apparatus is required, but a rough method consists of placing a test-tube containing the oil in a freezing mixture and observing the temperature at which the oil ceases to flow by tilting the tube slightly. Care must be taken not to agitate the oil during the freezing process.

6. **Evaporation and gumming.**—Evaporation and gumming can be estimated fairly well from the glass-plate experiment, Pl. **126**, Fig. 2, by comparing the tracks on the glass after several hours or days. More detailed experiments can be made, if required, by placing a weighed sample in a watch-glass and noting the loss in weight due to evaporation and the increase in viscosity due to gumming, the sample being kept at its working temperature.

Mineral oils require a considerably greater period than animal and vegetable oils to give reliable results in this way. Mineral oil may thicken, due to the evaporation of volatile hydrocarbons; and concentrations of tar, resin, or asphaltic matter may render the oil sticky when so tested.

With the best qualities of mineral oil, however, no change whatever will be apparent after 24 hours' exposure to the air in the form of a thin film, and the evaporation at (say) 350° F. will not exceed 0·5 per cent.

PLATE 126.


LUBRICATION.
Fig. 1.
REDWOOD'S VISCOMETER
Fig. 5.
MICHELL BLOCK RIDING ON AN OIL WEDGE
Fig. 4.
AXLE BOX, WITH RECESSES FOR SOLID LUBRICANT
Fig. 2.
SLOPING GLASS VISCOMETER
Fig. 6.
SHAFT BEARING
Fig 7
BLOCK WITH SHARP EDGE SCRAPING OFF OIL
Fig 9.
VIBRATING-NEEDLE LUBRICATOR
Fig 8
BADLY DESIGNED & ASSEMBLED JOURNAL BEARING
PENSKY-MARTIN FLASH-POINT APPARATUS
Fig 3
Fig. 11.
GREASE PUMP
Fig. 10
SPRING CONE LUB.
Fig 12.
STAUFFER'S LUBRICATOR
Fig 13.
REISERT SPRING LUBRICATOR
Fig 14.
PNEUMATIC GREASE CAP

7. Hard asphalt content.—If they comply with the British Standard Specification, mineral lubricating oils should not have any asphalt content, except in the case of steam cylinder oils, when the maximum percentage allowed is 0·5.

The importance of this requirement is due to the fact that asphalt does not distil but forms coke when the oil is heated, thus contributing to "carbonization."

The content is determined as follows :—

Ten grams of the sample of oil to be tested are dissolved in 100 c.c. of petrol, thoroughly mixed and allowed to stand for 24 hours. The whole is then filtered through an 11-cm. folded filter-paper and washed with petrol until the washings are colourless. The material on the paper is then dissolved in benzol, which is distilled off on a water-bath, and the asphalt is then dried in a steam oven for an hour and weighed.

8. Acidity.—Acid reaction can be tested with litmus paper, or by suspending a piece of polished tool steel in the oil for some days, when no rust or corrosion should be observed. A more decisive test is to spread some of the oil on a bright surface of the metal of which the bearings are made, leave it so for several days enclosed in a box away from dust, and then test the oil chemically for presence of dissolved metal.

It is very unlikely that mineral oils will give an acid reaction unless they are broken down due to the action of heat, moisture, dirt, &c.

9. Emulsification.—In cases where it is not possible to prevent the access of water to a lubricant, as in steam-engine cylinders, it is essential that the oil and water shall readily separate after having been vigorously shaken together. The more rapid the separation, the better the oil for use in all cases in which water contamination is possible. Animal and vegetable oils and some mineral oils when treated in this manner (as they are in engines), especially if a trace of lime be present, form a thick emulsion which ultimately becomes a tacky mass, totally unfit for lubrication.

In I.C. engines, too, the same trouble may occur, especially when water injection is practised, and in engines with water-cooled pistons. The lubricating properties of an oil-water emulsion are much inferior to those of oil alone, and the viscosity is very much in excess of that of either of the two components. Moreover, such an emulsion will not readily pass through the oil pipes, and may choke the suction side of the lubricating oil pump, thereby causing failure of the oil supply.

10. Keeping qualities of oil.—In modern machinery, provision is generally made for using the same oil over and over again, as, for instance, by means of a circulating pump.

It is very necessary, therefore, that the oil should retain the good qualities referred to above for long periods.

11. **Mechanical testing.**—The methods referred to above for checking the qualities of lubricants will normally suffice for service purposes, but to confirm the suitability of an oil for a particular purpose, it should be tried out in the actual machine for a continuous running period of some hours. In order to simulate actual running conditions, special testing machines are largely used in civil practice, but as these are not often likely to be met with at military stations they will not be further referred to.

12. **Solid lubricants.**—*Graphite.*—Flake graphite added in very small quantities to oil for bearings increases its lubricating qualities.

Graphite is not a lubricant in itself, but produces a very highly polished surface on the bearings, and so diminishes the friction should the metal surfaces come in contact. It is not suitable for regular use in the cylinders of internal combustion engines using electric ignition, since the graphite has a tendency to bridge the spark gap.

White metals.—As regards the use of white metals of a fairly plastic nature for lining bearings, careless fitting or distortion of the bearing may result in the concentration of excessive weight in certain spots, and consequent destruction of the oil film there. Local heating follows, and the plasticity of the bearing metal is thereby sufficiently increased to enable it to flow slightly, until the pressure at the high spots has been equalized. Thus, in circumstances in which a hard bearing might seize and damage the journal, one lined with soft metal may only run warm for a time and readjust itself before any damage occurs.

13. **Forms of bearings.**—The general form of all bearings should be such as to assist in the introduction of the oil film between the surfaces. The Michell thrust-block sector, shown on Pl. **126**, Fig. 5, exemplifies this. The easy curve at the leading edge smooths down the oil without scraping it off, and the variable wedge-shaped space between the surfaces corresponds with the gradual squeezing out of the oil under the load. Pl. **126**, Fig. 6, shows how the same principle applies in a well-shaped cylindrical bearing with a properly shaped oil groove at the non-pressure side, in this case the top.

At the point where oil enters a bearing, the edges of the hole should be chamfered to facilitate the entrance of the lubricant to the bearing surface. Oil-distributing grooves should be cut in the bearing and their edges also well chamfered so as to allow the oil an easy passage to form a film. If the

edges are sharp, a scraping action may be set up and altogether destroy the film. Grooves should be shallow, and not cut too near the ends of the bearing, or the oil will run out too easily.

Pl. **126**, Fig. 7, illustrates the effect of a friction block with too sharp a leading edge, which scrapes off the oil film and then tends to dig in. Pl. **126**, Fig. 8, shows the same defect in a journal bearing, where the oil groove, A, is in the wrong place and the edge is sharp. Further, the half-bearings, having sharp edges, B, scrape off the oil, while the packing, C, projecting, acts also as a scraper. Such a bearing will run hot and eventually seize. *See* also Sec. **148**, para. 4, and Sec. **149**, para. 9.

The effective area should be sufficient to ensure that at the heaviest working load the oil film cannot be squeezed out.

157. *Systems of lubrication*

1. **Hand oiling.**—The elementary principle of providing a hole in a bearing into which an attendant sometimes pours a few drops of oil is nearly useless. Where it exists, something better should be fitted at the first opportunity to ensure a continuous supply.

2. **Oilcups.**—A glass cup containing a fair quantity of oil is sometimes fitted, and generally some means for cutting off the oil supply when the machinery is not running. This is satisfactory provided it is clearly visible, and the attendant is careful to see that some oil is always in the cup and that it is falling regularly, indicating that it is probably going into the bearing. Oil squeezed out at the ends of the bearing should be caught in a tray. It can then be strained and used again, but some is always lost.

3. **Vibrating needle.**—The vibrating-needle type of cup lubricator has a needle or wire of slightly less diameter than the oil-hole, which rests on the journal surface, Pl. **126**, Fig. 9. The annular passage left open is not large enough to allow any material quantity of oil to flow when the machinery is at rest. When it is running the vibration causes the needle to jump, and it works oil slowly but continuously down to the bearing.

4. **Valve type.**—The spring-valve type has a cone valve normally kept closed by a spring, and provided with a catch of some type whereby the valve can be kept open when the machinery is running, Pl. **126**, Fig. 10.

5. **Grease caps and pumps.**—Where slow movement, difficulty of access, or the necessity to avoid sprinkling oil about renders it necessary to use solid or semi-solid grease as a

lubricant, screw-down grease caps are normally employed, or some other means of forcing in the grease.

i. Where movement is small and the grease tends to remain well in the bearing, it may be sufficient to fill the bearing by means of a grease pump at stated intervals. Spring shackles of vehicles are sometimes so treated, as shown on Pl. **126**, Fig. 11. The screwed nozzle, A, of the pump fits a nipple or hole, B, in the shackle pin, threaded for the purpose, which is normally closed with a cap or plug, C.

ii. Simple grease caps or Stauffer lubricators, as shown on Pl. **126**, Fig. 12, may be fitted in accessible places. At intervals the cap should be given a partial turn to force a little more grease into the bearing. Such caps should be large.

iii. The Reisert lubricator, illustrated on Pl. **126**, Fig. 13, provides more continuous renewal of lubricant. The spring plunger, P, yields to the pressure of the grease when the cap is screwed down slightly; it then returns gradually, forcing grease slowly into the bearing.

iv. The lubricator shown on Pl. **126**, Fig. 14, acts on the same principle as (iii), but air imprisoned in the extension, D, takes the place of the spring and plunger.

6. **Sight-feed lubricators.**—In cases where the lubrication of a bearing is of great importance, such as the main bearings of an engine, if no automatic system of lubrication is provided, it is advisable to fit a short length of glass tube, G (Pl. **126**, Fig. 10), between the oil reservoir or cup and the bearing, so that the oil can be seen dripping from the nozzle, N. Thus a failure or insufficiency in the provision of oil is more likely to be noticed at once before the bearing begins to suffer.

7. **Ring lubrication.**—Modern bearings are usually designed to oil themselves continuously from a sump containing a large quantity of oil, to which all oil squeezed out is returned to be used again. There is thus no likelihood of starving the bearing of oil, and the actual amount of oil used in a year is very much less than that used in the hand-oiled types.

Pl. **120**, Fig. 5, shows a modern shaft-bearing with ring-oiling. A loose ring, hung on the shaft and dipping in the oil sump, is always lifting oil and spreading it on the shaft. An oil groove on the non-pressure side distributes this oil along the length of the journal. Oil squeezed out merely pours into the sump again, through slots provided between

the bearing itself and its case. Since the oil never goes outside the bearing shell it does not gather grit and dust, and little evaporation can take place. Such bearings are no more expensive than the older type, and are much more reliable.

8. **Forced lubrication.**—In modern high-speed engines and in expensive machinery of other kinds, the ring, described in para. 7, is sometimes replaced by a small pump which draws oil from a sump, generally in the bed-plate, which may contain several gallons of oil. The oil is drawn in through a strainer, and is forced first through a filter and then through pipes to every important bearing in the engine.

Moving bearings, such as those of crank pins and gudgeons, are often supplied through small holes drilled through the crankshaft, connecting rod, &c. All oil squeezed out pours down, or is flung away against the crank chamber walls, and so pours back into the sump. Here any grit picked up either settles down or is strained out. Gum or soap formed is extracted in the filter. Not only does the oil lubricate the bearings, but the circulation is rapid and copious, so that it carries away heat and so keeps the bearings cool. The system can be clearly seen on Pls. **51, 52** and **114.**

9. **Splash lubrication.**—In many small high-speed engines, oil is freely splashed all over the working parts by allowing the big-ends, or scoops attached to them, to dip at every revolution into a trough of oil. In simple engines the oil merely drips down again into the trough. In many designs an improvement is made by allowing the oil to collect in a sump, from which a pump draws it out through a strainer and replaces it into the trough. Thus the level of oil in the trough is kept constant, provided there is oil in the sump. Splashing alone will not lubricate bearings. Above each bearing there must be some vessel, or a recess in the casting, to catch the oil, and a passage must lead the oil into the bearing in the right place. This is not always easy to arrange, as, for instance, in connecting-rod big-ends, where rapid movement tends to fling away oil rather than collect it in any catcher provided.

In Willan's high-speed steam engine this difficulty was overcome by providing an open cap to the big-end, so that part of the crank pin is bare, and this dips into the oil sump at each revolution.

10. **Combined systems.**—Combinations of the above systems are in common use in engines. Thus, in some cases, the main bearings and big ends only are supplied with oil under pressure, and splash is relied on for the cylinder and the gudgeon pin.

For further particulars, *see* Sec. **72.**

158. *Selection and care of lubricants*

1. British Standard classification of lubricating oils.—There is such a bewildering variety of proprietary brands of lubricating oil that it is quite useless to attempt to classify them.

Fortunately, B.S.S. 210 is available for pure mineral lubricating oils, and if it should become necessary to purchase on the recommendation of a manufacturer for a particular engine, this specification should be used as a safeguard when asking for quotations.

2. Service lubricants.—For most purposes under normal service conditions, suitable lubricants can be obtained from the R.A.O.D. or the R.A.S.C. (in the case of oils suitable for M.T. only). Their nomenclature and general characteristics are given in Table **ZA.** It will be noted that the various types are distinguished by a letter and a number, the letter " M " signifying " mineral," and " C " " compound," and the number the approximate *British Standard nominal Viscosity,* which is the Redwood value at 140° F.

The *Pour-point* is not given, but it may be noted that for use in refrigerating plants the pour-point should be below 0° F., and for I.C. engines below 30° F.

3. Storage and handling of lubricating oils.—The importance of exercising extreme care in the storage of oil drums and barrels, of marking them correctly, and of keeping the various kinds apart, cannot be over-emphasized. The drums should, whenever possible, be stored under cover and the bungs should be kept in position when the oil is not actually being poured out. Every possible precaution should be taken to avoid the admixture of dirt with the oil when it is poured from the drum, and at the same time all containers through which the oil may be passed should be clean and free from water. Bung wrappings and chippings from broken bungs should not be allowed to pass together with the oil into the engine. Carelessness in handling, with consequent contamination of the oil, may cause serious mechanical breakdowns on an engine. In the field it will not always be possible to store the oil properly and further, owing to the lack of technical knowledge on the part of storemen, oils may occasionally be issued under the wrong name. It will, therefore, be advisable to test the contents of a drum before use, making use of whatever facilities may exist. A good deal can be done by comparison with oil known to be suitable for the purpose in view.

If the oil has been stored in the open for some time, the following procedure may be followed with advantage :—

The drum should be allowed to stand for some hours, and

Vocab. No.	Composition of lubricant	Flash-point not below ° F.	Average viscosity, *i.e.* seconds required to pass 50 c.c. redwood ° F. 70	140	200	Remarks
M 60	Light non-freezing mineral	325	305	61	—	For refrigerating plant. Non-freezing 0° F.
M 70	Light mineral	375	390	73	43	For stationary low-compression engines and R.F. instruments.
M 75	Mineral	375	385	73	43	For steam turbines.
M 80	Non-freezing mineral	330	575	80	—	For small arms, machine guns, bicycles and general purposes. Non-freezing at 0° F.
M 100	Heavy mineral	400	630	105	50	For high-compression oil engines.
M 120	Light mineral	375	1000	123	55	For motor cars.
M 220	Heavy mineral	375	—	220	75	For motor cycles.
M 225	Light mineral	430	—	225	75	For steam cylinders and bearings.
M 265	Extra heavy mineral	400	—	265	85	For motor lorries.
M 600	Heavy mineral	460	—	600	150	For steam cylinders, bearings, gear-boxes, back axles.
M 800	Extra heavy mineral	500	—	800	200	For steam cylinders, bearings, gear-boxes, back axles (for higher pressures and superheated steam).
C 70	Compound (" Rangoon ")	360	300	70	40	Mineral oil 2 parts ; fatty oil 1 part.
C 120	Medium compound	375	1000	120	55	For stationary high-speed I.C. engines—mineral oil 97 parts ; lard oil 3 parts.
C 160	Compound	350	450	—	—	Marine engines other than forced lubricating machinery in W.D. steam vessels, steam rollers and tractors—mineral 80–85% ; rape oil 15–20%.
C 170	Heavy compound					For stationary high-speed engines—mineral oil 97 parts ; lard oil 3 parts.
Grease C.C.	Lime soap, lard oil, and petroleum ..		Semi-solid			For cool climates.
Grease H.C.	Lime soap, lard oil, petroleum, 4% graphite	—	Solid	—	—	For hot climates.
Grease M.T.	Lime soap, lard oil, and petroleum ..	—	Solid	—	—	For M.T. vehicles.

then samples should be taken, by means of a tube, from (*a*) the top, (*b*) half-way down, and (*c*) the very bottom of the drum. The samples may be drawn by closing the top of the tube by finger pressure, plunging the tube to the required depth, removing the pressure to allow oil to rise in the tube, applying the pressure again, and quickly withdrawing the tube.

(*a*) will show whether a light oil has been mixed with a heavier one.
(*b*) will be representative of the bulk of the oil.
(*c*) will contain an excess of any heavy impurities present, such as mud or water.

Mud or water can be removed by drawing off the oil after standing for a day or two, taking it from a point a little distance above the bottom. Lighter impurities can be largely removed by forcing the oil through a fine gauze filter.

159. *The recovery treatment of lubricating oils*

The consumption of lubricating oil in a heavy-oil engine when running at full load in good condition, is about 0·006 lb. per B.H.P.-hour. Under average running conditions, under varying loads, this figure is increased to about 0·01 lb. per B.H.P.-hour. Assuming a station with 500 B.H.P. installed and a plant load factor of 50 per cent., the annual consumption, based upon 2,000 hours' running, would be $500 \times 2{,}000 \times 0{\cdot}01 = 5{,}000$ lb., which, at 2/- per gallon would cost $\frac{5{,}000}{9} \times \frac{2}{20} = £56$.

Of this consumption, less than half is actually consumed in the engine, and the rest finds its way to the sump contaminated with fuel oil, carbon, dirt, and perhaps water.

Now the actual use of oil, purely for lubricating purposes, does not in any way exhaust its lubricating properties, and providing that the fuel oil contamination is not excessive, the oil can be purified and used over and over again.

There are numerous designs of filtering and purifying apparatus, in all of which the oil is heated to from 150° to 200° F. to facilitate the operation.

In some experiments which were carried out at Gosport a few years ago, the following types were tried :—

A. *The Wells (Cotton Pad) Filter.*
B. *The De Laval Centrifugal Separation (Centrifugal Process)* (approx. cost to deal with 15 gals. an hour, £40).
C. *The "Streamline" Filter* (using the Hele-Shaw principle of edge filtration) (approx. cost to deal with 10 gals. an hour, £55).
D. *The Auto-Klean Strainer* (approx. cost to deal with 100 gals. per hour, £6 15*s*.).

The *Streamline* filter (size 07) comprises a reciprocating air pump driven by a 1/8-H.P. motor and a 750-watt immersion heater incorporated in the filtering vessel. It contains 6 filter packs, each about 12 in. long, composed of a large number of discs of doped paper, about $1\frac{1}{2}$ in. in diameter, compressed together by springs. During filtration, solid matter in the oil is arrested at the edges of the paper, the oil passing between the sheets to a hollow at the centre. The dirt is dislodged during the cleaning operation by blowing compressed air in the reverse direction by the movement of a lever.

The *Auto-Klean* strainer is designed to take the place of the usual wire gauze filter in the circulating oil system of an engine using forced feed lubrication.

In this strainer, the oil is forced under pressure through a series of five slots in a cartridge built up of a large number of thin circular metal discs mounted on a central spindle. The dirt is intercepted at the edges of the discs, and in order to clean the slots, the central spindle is rotated. This revolves the cartridges against a series of stationary cleaning blades which engage between the discs and so scrape the dirt from the slots. The dirt falls into a sump which is emptied periodically.

The following conclusions were arrived at and recommendations made as a result of the Gosport experiments :—

i. For the periodic filtering in bulk of crankcase oil containing very little water, the Streamline filter is more efficient than the centrifugal filter, as by a single process it produces a filtered oil which has the appearance and properties approximating very closely to those of new oil.

ii. Where water is present in any quantity, the centrifugal separator is the better machine, but the filtered oil is much darker than the original new oil, owing to the presence of colloidal carbon which the apparatus is unable to remove.

iii. For the continuous filtering in a constant circulation system, the Auto-Klean strainer, although not having the efficiency of the much more expensive centrifugal and Streamline filters, is far more efficient than the usual gauze filter which it is designed to replace. More experience is necessary to ascertain to what extent it is worth fitting these filters to the lubrication systems of various engines. For fuel oil, the Auto-Klean strainer is very effective and can be conveniently applied to any part of the fuel system.

iv. The provision of both Centrifugal and Streamline filters is worth consideration for large engine installations for the filtering of lubricating oil having appreciable water content, in combination with Auto-Klean strainers for the filtering of the fuel oil.

To the above it may be added that on large generating sets in which forced lubrication to all parts with a continuous circuit is employed, it is now considered preferable to insert the filter in the circuit and so treat the oil continuously, instead of at intervals when it has reached a poor condition.

The above considerations apply principally to fairly large generating stations using heavy-oil engines. In small stations it may be best to dispose of the oil which drains from the engine-bed by adding it to the fuel oil. If roughly filtered in a cotton-pad type of filter, however, the oil can be used for hand-oiling round the engine.

In the case of small petrol and petrol-paraffin plant it will seldom be worth while to adopt recovery processes, particularly as in this case the lubricating oil is subject to contamination with the lighter fuels. In large garages the installation of filters may well be worth while, a blast of air being employed in the apparatus to carry off the lighter fractions of petrol contamination.

For Bibliography, see page 690.

CHAPTER XXXIV

COMPRESSED AIR

160. *General principles*

1. **Uses.**—Compressed air is used extensively for the transmission of power in the following work :—

i. In the operation of hand drills in rock in mining operations, as fully described in Military Engineering, Vol. IV.
ii. For drilling, chipping, and riveting in boiler shops, shipyards, and constructional engineering, such as in steel bridges.
iii. In foundries for vibrating moulding machines, core-breaking, and cleaning castings.
iv. For pile-drivers.
v. For lifting water out of deep bore-holes, as described in Military Engineering, Vol. VI.

Reciprocating compressors only will be considered, as single-stage rotary compressors can only be used up to 30 or 40 lb./sq. inch, and two-stage rotary compressors are heavier, bulkier and more costly than reciprocating compressors for the same duty.

2. **The compressor.**—A simple slow-speed type of reciprocating air compressor is shown in Pl. **127**, Fig. 1. Air is drawn into a cylinder by means of a piston provided with rings, arranged generally as for an internal-combustion engine. It enters through an inlet valve, I, in the piston, which should be of large diameter, of the lightest possible construction, and free to open when the pressure in the cylinder is reduced in a very small degree below that of the atmosphere.

At the end of the suction stroke the cylinder will not be quite filled to atmospheric pressure on account of the inertia of the air, which causes it to lag behind the piston. The inlet valve will, therefore, remain open until the pressure inside and outside the cylinder are nearly equal, and by this time the piston will have commenced its compression stroke. Therefore, the volume of air drawn into the cylinder will be slightly less than the actual displacement of the piston.

The compression stroke now takes place. The air in the cylinder is compressed adiabatically, or nearly so, until its pressure is slightly above that in the delivery pipe, P. A delivery valve, D, similar to the inlet valve but opening

outwards, now opens and permits the air to flow into the delivery pipe, and, in consequence, no higher pressure can be produced in the cylinder.

In practice, there must be some clearance between the piston and the cylinder head at dead centre. When the compression stroke is completed, this clearance space will be full of air at approximately the same pressure that exists in the delivery pipe.

On the return, or suction, stroke the delivery valve will close. The inlet valve will not open until the air left in the clearance space has expanded to a little below atmospheric pressure. When the pressure in the cylinder has so fallen, the inlet valve will open and admit air until a little after outer dead centre, as at the end of the suction stroke described above.

3. **Volumetric efficiency.**—Let V_1 represent the whole volume of the cylinder, including the clearance and the volume swept out by the piston, V_2 the volume of the cylinder when the inlet valve closes, V_3 the volume when the delivery valve opens, V_4 the clearance volume, and V_5 the volume when the inlet valve opens.

Then, referring to Pl. **127**, Fig. 2, the amount of air, measured in volume at atmospheric pressure and temperature, that is drawn in per stroke is $V_2 - V_5$, represented by *ac*. The actual displacement of the piston is $V_1 - V_4$, represented by *db*.

The volumetric efficiency of the compressor is the ratio between the volume of air drawn in and the actual displacement of the piston, or $\frac{ac}{db}$. This figure is proportional to *ac* (which varies inversely as the clearance space and nearly inversely as the maximum pressure attained).

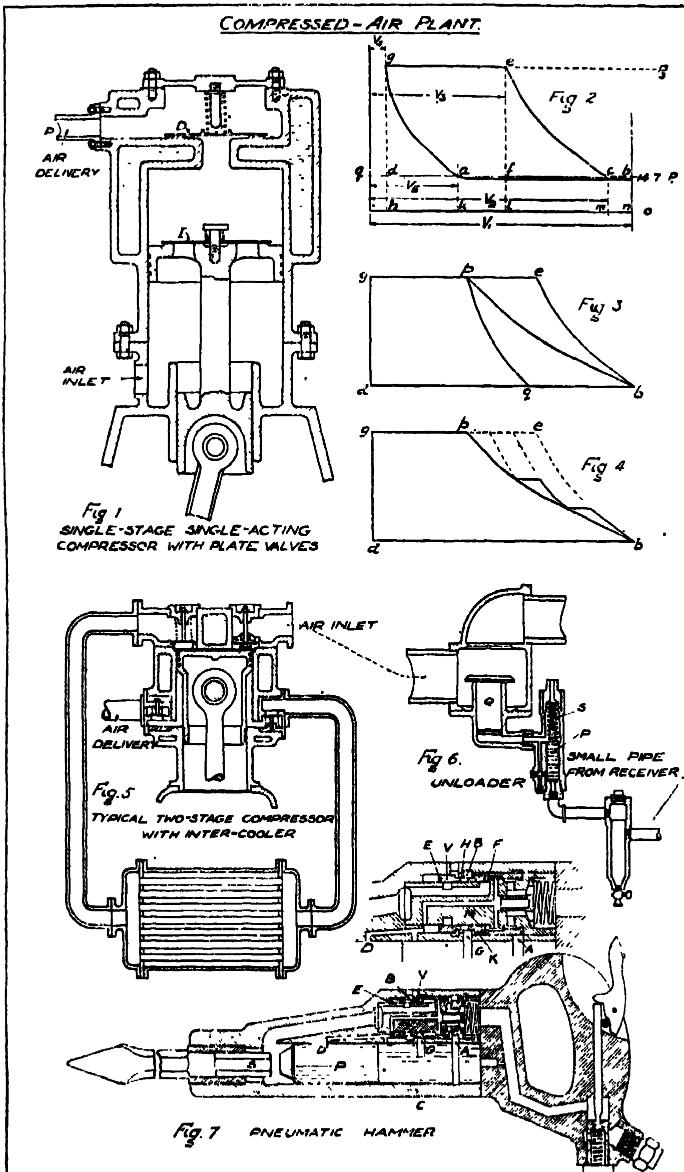
Its value is 85 to 90 per cent. in modern machines. The volumetric efficiency determines the size of machine required for a given duty, but does not appreciably affect the energy efficiency.

4. **Work done.**—The work done in compressing the air in the cylinder to P_2 lbs. per square inch, at which the delivery valve opens, is represented by the area *b c e l n*, and the work in forcing air out of the delivery valve by *e g h l*.

The air in the clearance space does work *g h k a* during the return stroke up to the time of opening of the inlet valve, after which the atmosphere does work *a k n b* in driving air into the cylinder.

The net work done is, therefore, *b c e g h n*—*b a g h n*, or *b c e g a*, of which only *c e g a* is necessary, and the area between *a* and *b* below the atmospheric line represents a loss

PLATE 127.


COMPRESSED-AIR PLANT.
AIR DELIVERY
AIR INLET
Fig 1
SINGLE-STAGE SINGLE-ACTING COMPRESSOR WITH PLATE VALVES
Fig 2
Fig 3
Fig 4
AIR INLET
AIR DELIVERY
Fig. 5
TYPICAL TWO-STAGE COMPRESSOR WITH INTER-COOLER
Fig 6.
UNLOADER
SMALL PIPE FROM RECEIVER
Fig. 7 PNEUMATIC HAMMER

due to the imperfections of the valves. This area depends upon the nature of the valves and the piston speed, while the area *c e g a* depends upon the pressure to which the air is compressed. The cylinder head should be so designed as to leave the minimum of clearance space.

5. **Heat losses.**—The work done in compressing air adiabatically, as in para. 4, appears partly in heat, the temperature of the air being increased in theory to the extent of r^{n-1}. (*See* Sec. **63.**) This heat is given up, partly to the cylinder walls and partly to the receiver in which the air is temporarily stored and to the pipes which convey it to the machine.

In consequence, whereas the compressor has done net work approximately equal to *c e g d* on Pl. **127**, Fig. 3, only energy to the amount of *c p g d* is now available for use in the machine or tool if the air could be expanded isothermally. Actually the air, by expanding in the machine or tool nearly adiabatically, is cooled further, and will only give back work approximating to *q p g d*.

6. **Multi-stage compressors.**—In order to reduce the loss represented by *c e p*, compressors are often compounded like a steam engine, or may be three-stage, with three cylinders of graded sizes, generally arranged to compress in ratio $\sqrt[c]{r}$, where r is the total ratio of compression $(\frac{V}{V_1}$, where V= original volume and V_1 = volume after compression) and c is the number of cylinders.

Pl. **127**, Fig. 4, shows how this economizes by reducing the loss, if the air is allowed to cool down after each stage of compression. .

7. **Water jackets.**—If the air in a single-stage compressor is compressed adiabatically in ratio 4, the resultant pressure, P_1, will be $P\left(\frac{V}{V_1}\right)^n$ or $14{\cdot}7 \times 4^{1{\cdot}4} = 103$ lbs., or 88 lbs. gauge, and the temperature, T_1, of the air, if it starts at 60° F. or 519° A., will be $T\left(\frac{V}{V_1}\right)^{n-1}$ or $519 \times 4^{\cdot 4} = 904°$ A. or 445° F. At this temperature, many lubricating oils will ignite spontaneously. In order, therefore, to enable the piston to be lubricated without danger of an explosion, which would probably spread to the receiver where there would be much oil vapour, it is necessary to keep the temperature below 350° F. To this end the cylinder head is always water-cooled ; and a machine designed to compress air to much above 100 lbs. gauge must be of the two- or three-stage type. Moreover, to ensure that the air is cool at the commencement of each

stage it is passed through an inter-cooler arranged like a surface condenser for a steam engine, in which it parts with most of its excess heat to cooling water circulated around tubes, as shown diagrammatically on Pl. **127**, Fig. 5, which illustrates a two-stage compressor, in which the first stage of compression is carried out above the piston and the second stage in the annular space between the piston and surrounding trunk.

8. **The unloader.**—The point in the compression stroke at which the delivery valves open is shown in para. 2 to be entirely dependent upon the pressure existing in the delivery pipe. If, therefore, air is being pumped into a receiver from which none is allowed to escape, the pressure in the receiver will continue to rise until it is sufficient to prevent the air-delivery valves opening at all. In this case, referring to para. 3, the ratio of compression in the cylinder will be $\frac{V_1}{V_4}$. No further air will be pumped through, because the air in the clearance space at inner dead centre will expand and keep the cylinder full during the suction stroke, at the end of which the pressure will not be sufficiently below atmospheric to allow the inlet valves to open. But this great rise of pressure in the receiver would be dangerous, and in any case the compressor would have done unnecessary work. Receivers are, therefore, fitted with safety valves, and compressors are fitted with a device known as an unloader, in which the air in the delivery pipe is allowed to press upon a piston, P on Pl. **127**, Fig. 6, controlled by an adjustable spring, S. Whenever the pressure exceeds that for which the unloader is set, the piston, P, moves slightly, and in so doing allows the compressed air to push up the plunger, Q, which closes the air inlet of the compressor. Thus less air, or none at all, is taken into the cylinder to be compressed until the pressure in the delivery pipe falls again; meanwhile little work is being done, except that required to overcome the friction of the machine.

An objection to this method of governing is that a partial vacuum is formed in the cylinder on the down-stroke, and this causes an unnecessary quantity of lubricating oil to be drawn in past the piston-rings. A better method, which is employed in some designs, is to hold the suction valve from its seat when a predetermined pressure is reached in the receiver. By this means air is simply drawn in and exhausted at atmospheric pressure.

Petrol engine-driven compressors usually have in addition an arrangement whereby the engine is throttled down to slow speed, thus effecting a further saving in petrol.

9. **Receiver.**—It is usual, when compressed air is used for machine tools, to pass the air from the compressor delivery valve into a receiver, similar to a plain cylindrical steam boiler.

The principal objects of a receiver are :—

i. To minimize pressure fluctuations due to the piston pulsating effect.
ii. To cool the air before it passes to the main, thus causing part of its moisture content to be deposited.
iii. To serve as a reservoir of energy.

The small receivers normally fitted to small stationary and portable plant fulfil the first two functions, but a receiver of abnormal size is required to serve as an appreciable reservoir of energy. For example, consider the case of a compressor rated at 100 cubic feet of free air per minute at a pressure of 100 lb./sq. inch. A receiver necessary to deal with an overload of 25 per cent. for 1 minute with a drop in pressure of not more than 15 lb./sq. inch, must have a capacity of 25 cubic feet (say) 2 feet in diameter and 8 feet in length.

A receiver must be fitted with a pressure gauge, a drain-cock through which accumulations of water and oil can be removed, and also a safety valve to release the pressure should the unloader on the compressor fail to operate.

161. *Compressor sets*

1. The older slow-speed types of compressor are usually belt-driven. The direction of rotation is not important in the case of those fitted with automatic valves, provided the crosshead is capable of taking the diagonal thrust of the connecting-rod equally on either side.

Compressors are occasionally fitted with mechanically-operated valves, and can then only be run in one direction, except by considerable alteration of the valve gear. If compressors are run at faster speeds than that for which they are intended, the power taken increases more rapidly than the amount of air delivered, which does not increase proportionally to the speed.

For service purposes, compressors are often mounted on steel-joist frames together with a flexibly-coupled engine, generally of the lorry type of petrol engine. In such sets the engine should be of a R.A.C. rating at least double the brake horse-power required to drive the compressor at its normal output, after allowing for transmission losses.

For air-lift purposes, the receiver need not be of large capacity, and may conveniently be mounted upon the same frame. The whole set is then portable by motor lorry.

2. Pl. **128** shows a type of portable compressor. It is a twin-cylinder single-stage compressor direct-coupled to a petrol engine. The makers will replace the petrol engine by a high-speed Diesel engine if desired.

The rated output is 100 cubic feet of free air per minute at a pressure of 100 lb./sq. inch and a speed of 1,200 r.p.m. The piston displacement is 116 cubic feet per minute. The plant is suitable for operating two road breakers *or* two rock drills *or* four smaller tools, such as rammers and riveting and caulking hammers.

The assembly of the equipment is slightly different from that in the usual commercial pattern, since it has to conform to military requirements in respect of overall width at axles to enable it to be run into the well of a standard six-wheeled M.T. vehicle. The air receiver is a little shorter than shown in the makers' catalogue—also on account of width limits. Also, the receiver is situated between the engine and compressor, instead of outside the cab as in the makers' standard design.

The weight of the unit complete is 19 cwt.

The overall length is 6 ft. 9 in. and the height 4 ft. 4 in., approximately.

The compressor is of the *sleeve valve* type (Pl. **129**), in which the passage of the air into and from the cylinder is controlled by a reciprocating sleeve sealed by piston-rings and operated by an eccentric turned solid with the crankshaft. Many modern high-speed reciprocating compressors are of this type.

The air inlet port is a slot in the cylinder wall which is brought into communication with the interior of the cylinder at the correct time by corresponding ports in the sleeve itself.

By this means it is possible to make the area of the inlet opening to the cylinder three or four times greater than that obtained with a plate valve.

When the piston is about half-way up on the compression stroke, the sleeve opens a port formed by a special type of sealing ring, and this puts a small water-jacketed annular space into communication with the cylinder. The object of this space is to increase the capacity of the cylinder and also to increase the cooling effect.

At the end of the compression stroke the sleeve cuts off the annular space from the cylinder, and the clearance space between the top of the piston and the cylinder head is only about 2 per cent. of the volume swept by the piston (in plate valve machines the clearance space is usually 5–6 per cent.), and therefore the volumetric efficiency is high.

PLATE 128

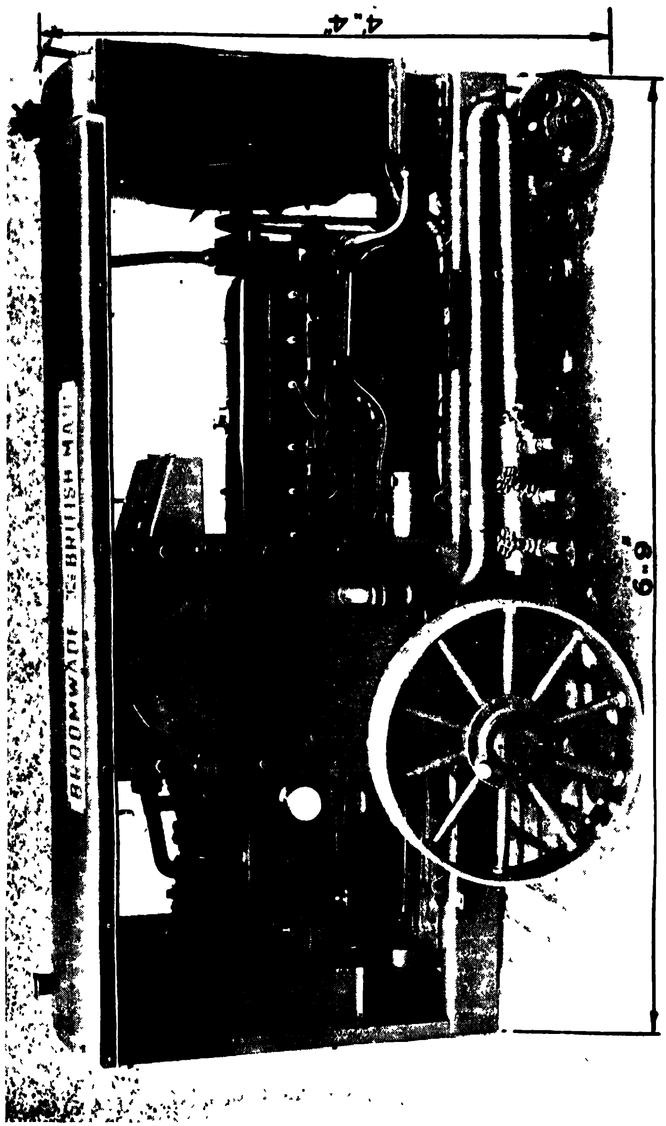
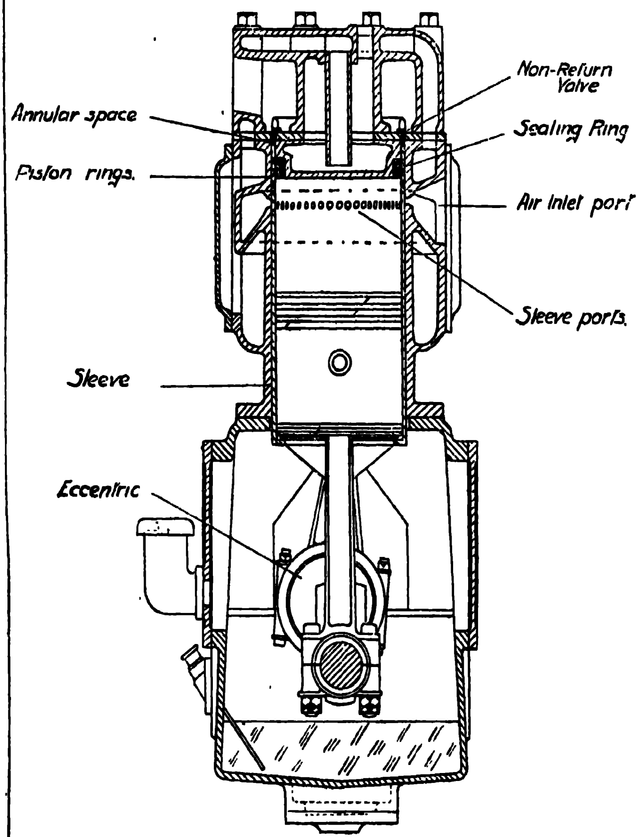


Plate 129.



SECTIONAL ILLUSTRATION
OF
SLEEVE VALVE COMPRESSOR.

The eccentric is set approximately 130° behind the crank-pin, so that when the piston is on the suction stroke the sleeve continues to travel upwards until the air in the annular space is delivered into the service line through the non-return valve.

The non-return valve, which is a thin, flat plate, is larger in diameter than the cylinder, and owing to its size provides an opening of ample area with a very small lift. Due to the action of the sleeve, the valve has 160° of crank angle to open and close in, as compared with about 40° or so with an ordinary plate valve. Therefore, although the compressor is running at 1,200 revs. per minute, the non-return valve is operating under conditions similar to those of an ordinary plate valve compressor running at 300–400 r.p.m.

3. **Power required.**—The theoretical horse-power required to compress 1 cubic foot of free air per minute adiabatically to an absolute pressure of P_1 lb. per square inch in a single-stage compressor, is:

$$\text{H.P.} = \frac{144Pn}{33{,}000\,(n-1)}\left\{\left(\frac{P_1}{P}\right)^{\frac{n-1}{n}} - 1\right\}$$

Taking n as 1·408 and P = 14·7 lb./sq. inch,

$$\text{the I.H.P.} = 0{\cdot}22\left\{\left(\frac{P_1}{14{\cdot}7}\right)^{0\cdot29} - 1\right\}$$

If the mechanical efficiency of the compressor is 90 per cent., the B.H.P. required to compress 100 cubic feet of free air per minute to a gauge pressure of 100 lb./sq. inch

$$= 100 \times \frac{0{\cdot}22}{0{\cdot}9} \times \left\{\left(\frac{114{\cdot}7}{14{\cdot}7}\right)^{0\cdot29} - 1\right\} = 20 \text{ B.H.P. approx.}$$

162. *Care, working and management of air compressors*

1. **Valves and cylinder head.**—It will be seen from Sec. **160**, para. 4, that a compressor depends very much for its efficient working upon the freedom of its valves to open immediately any excess pressure develops upon their under sides, and upon their quick closing and airtightness when the pressure is reversed.

The valves are, therefore, of very light construction, and depend for their tightness upon the accurate metal-to-metal fit of their lower surfaces upon the valve seatings. Pl. **127**, Fig. 1, shows a thin-plate valve.

All valves should be cleaned at least once a week. This should be no perfunctory matter, but a careful washing with soap and water, after which the valves and seatings should be

rubbed dry and clean with an absolutely clean cloth. On no account should cotton waste be used, since it is impossible to avoid leaving some threads of cotton, which are sufficient to hold the valves off their seatings. The slightest trace of grit will completely prevent the compressor from working, since air will flow back freely between the valves and their seatings unless there is true metallic contact.

Great care must be exercised in removing and replacing the valves, so that not the slightest burr is raised on any part of a valve or seating.

Petrol or paraffin must never be used to clean valves or cylinders. They could not be removed completely, and the vapour from them would explode easily at the pressures and temperatures that would exist when working. Soap and water will do all that is required.

Lubrication.—Since oil is very undesirable in the pipes, receiver, or tools, it should, consequently, be applied sparingly to the cylinders. One drop per minute to each cylinder is generally sufficient.

"Oil lubricating, heavy mineral (M100)" for high-compression oil engines, is suitable for pressures up to 100 lbs. per square inch. For higher pressures and multi-stage compression, special compressor oils should be used (not a R.A.O.C. supply).

It is most important that a suitable oil should be used. High flash-point alone is not sufficient safeguard against explosion. Under the conditions existing in the compressor, unsuitable oils may partially break up, producing volatile components. Explosions have been known to occur in compressors when the maximum temperatures which could have been produced by the compression were considerably lower than the tested flash-point.

2. **Receivers.**—The receivers for compressed air are generally built up of riveted plates like a steam boiler. They should be inspected, tested, and kept in repair in precisely the same way. *See* Sec. **115**.

Safety valves should be tested at regular intervals.

Receivers should be painted externally and internally when possible.

3. **Machine parts.**—The crankcase should be filled daily to the correct level, and the oil changed periodically. All bearings should be examined and adjusted similarly to those of an I.C. engine.

4. **Installation.**—A compressor should be treated in every way as an I.C. engine as regards siting and installation. The receiver should be regarded much as a steam boiler, and be similarly protected from the weather; if placed outside the

engine room or shop, it should be kept cool by at least a roof to keep off the direct rays of the sun, and preferably also by a through draught. The cooler it is kept the less the danger of explosion through ignition of the oil vapour it must contain. The air should be taken from a cool situation outside the building. The opening of the inlet, protected from dust, &c. by wire gauze, should be at least 7 feet above ground.

5. **Selection of plant.**—It is advisable to look ahead, and to instal a machine of sufficient power to meet not only the immediate demands, but also any further load that may be required later.

Compressors are difficult to keep in order, and will seldom give in actual service the output obtained upon the test-bench.

6. **Alterations to compressors.**—A well-built compressor can be made to deliver a smaller quantity of air at a correspondingly higher pressure by altering the tension of the spring in the unloader. The power taken is then considerably increased, and the engine of a self-contained set may be unable to take the extra load unless a throttle-valve, fitted in the inlet pipe of the compressor, is partly closed. The result of this is to diminish in a very large degree the amount of air delivered.

For such purposes as forcing the first blow of air into a deep bore-hole with an airlift pump this expedient will suffice, since only a small quantity is needed to start the flow, after which a lower pressure is sufficient, provided the delivery of air then increases.

163. *Pneumatic or compressed-air tools*

1. **Uses.**—Tools driven by compressed air may be used wherever the portability of the tools is of paramount importance. The principal reasons for their use is that they are little heavier than those designed for manual power alone, that they can do work much faster than can be done by hand, and that they are very portable, since the power is transmitted to them through comparatively light flexible pipes.

For such purposes as scaling boilers, chipping plates *in situ* in boilers, riveting boilers and bridgework, breaking the cores out of heavy castings, drilling and chipping stone in mines, quarries, tunnels, &c., and drilling plates *in situ* in boilers and bridgework, pneumatic tools are well adapted and are extensively used.

2. **Efficiency.**—The efficiency of pneumatic tools is generally very low. It will be seen from Sec. **160**, para. **5**, that a compressor works at a low efficiency owing to heavy heat

losses. A further loss occurs through the refrigerating effect of the expansion of the air in the tool.

In cold weather, some means must be provided to keep pneumatic tools from freezing up, especially in exposed places.

Another source of loss is occasioned by the flexible pipe connecting the air receiver and tool. To give the necessary portability, this pipe must be of small diameter, and may necessarily be very long, containing several couplings. There is, therefore, considerable loss in pressure owing to friction, and there may be very heavy losses of air due to leaks. It is seldom that much more than half the air compressed reaches the tool, and the pressure may also be halved by friction.

3. **Types.**—Pneumatic tools are broadly divided into three groups :—

i. Reciprocating tools or hammers.
ii. Rotary tools or motors.
iii. Tools which combine a reciprocating with a rotary motion, *i.e.* hammer drills.

Reciprocating tools are used for rock or concrete breaking, scaling, chipping, and riveting.

Rotary tools are used for drilling metal plates, tapping, screwing, etc., and other work to which electric motors could be more efficiently applied if electric power were available. The existence of a compressor, however, warrants the use of pneumatic motors when electric power is not already available.

Hammer drills are used for drilling holes in rock or concrete, *e.g.* for blasting purposes.

4. **Reciprocating tools.**—All pneumatic hammers, whether intended for use with chisels for scaling or chipping, with picks for coal-cutting or rock-breaking, or with snaps for closing rivets, work on the same essential principles.

A typical pneumatic riveter is shown on Pl. **127**, Fig. **7** ; although much variety in design may be found in hammers intended for different work and made by different manufacturers, the main differences lie only in such details as length of stroke and the relative amounts of power expended in the blow and the retraction, or return of the hammer to its original position.

In a riveting or chipping hammer it is important that every blow shall be powerful and decided, and delivered entirely upon the snap or chisel, that the return of the hammer shall be effected without shock to the hand of the operator holding the machine, and that the blows shall be delivered rapidly and regularly.

The hammer in the tool shown on Pl. **127**, Fig. **7**, consists of a heavy piston, P, fitting well but freely in a cylinder, C, and provided with a suitably hardened face to engage the head of the snap or chisel, S, as each blow is delivered. Compressed air is admitted alternately on either side of the hammer, P, so that it is alternately drawn away from the chisel and driven forward so as to strike it. The forward movement must be powerful. The valve, V, is designed, therefore, to admit compressed air freely to the back of the hammer through ports A, and to exhaust air freely from the front of the hammer through ports B. At the end of this stroke the hammer bares a port, G, which admits air to an annular piston, K, on the valve, V, and closes a port, D, thus accumulating air pressure from within on another annular piston, E. In consequence, the valve runs back and takes up the position shown inset. A small amount of compressed air is thus admitted through ports F to the front of the hammer, and simultaneously air is exhausted through the small ports G and H from the back of the hammer. The hammer, therefore, returns comparatively gently towards the retracted position, so that no heavy back-blow is given to the hand of the operator. Moreover, long before the hammer has finished its backward movement it has bared port D and covered port G, so that the valve commences to return to the position for driving the hammer forward. Thus the pressure on the front of the hammer is relieved, and compressed air entering at the back through A checks the hammer elastically and without allowing any positive shock to be transmitted to the hand.

In coal picks and concrete breakers a certain amount of return blow may be necessary to free the tool after each forward blow. This may be effected by a slight modification of the valve and ports.

In many hammers the valve guide, M, is dispensed with by placing the valve, V, upon and surrounding the hammer, the latter being drilled with the necessary ports, which are shown in M.

5. **Rotary tools.**—Pneumatic rotary tools consist generally of a high-speed motor with two, three, or four pistons, designed very much on motor-car engine practice, and similarly enclosed and balanced. The pistons are normally arranged in pairs, which may be opposed to give more perfect balancing.

The valve gear is generally somewhat similar to that described in para. 4, with the exception that the pistons are usually single-acting, and that, since no blow is desired, the working stroke is cushioned like the return stroke of a hammer.

Since the speed of the motor is generally much higher than that required in the drill, the power is usually transmitted by worm gear with a large reduction ratio.

The efficiency is very low, since the air cannot be used expansively to any great extent in so small an engine, and the leakage must necessarily be high in cylinders of so small a bore if the necessary clearance is allowed for free working.

6. **Hammer drills** are generally similar to reciprocating tools, but the steel is rotated slowly by means of a ratchet device, thus enabling a uniform circular hole to be drilled. To clear the debris from the hole, the steel is made hollow and the exhaust air is directed through it to the bottom of the hole. The usual sizes of the drill for use by one man without any fixed supports will drill holes up to about 2 inches diameter. It is necessary to taper the hole about $\frac{1}{8}$ inch for every 12 to 20 inches of depth, by using a diminishing series of steels. The rate of drilling varies greatly according to the nature of the rock, condition of tool, &c., but a rate of 8 to 12 inches per minute in moderately hard rock can be attained under favourable conditions. The steels require frequent redressing.

7. **Pneumatic tools** are normally made for an air pressure of 80 lbs. per sq. in. The consumption of air is a very variable quantity, but from 20 cu. ft. per minute for a small rotary drill up to 60 cu. ft. per minute for a heavy rock drill are reasonable figures.

8. **Care of pneumatic tools.**—Pneumatic tools must be kept well lubricated with a thin oil whose viscosity, at the low temperatures caused by the expansion of the air, is not sufficient to clog the valves, which are not positively operated, and depend upon very small differences of air pressure for their movement.

The parts are ground to a very accurate fit; therefore, in taking them apart for cleaning, the greatest care must be exercised in avoiding the slightest burring of surfaces or edges. Nevertheless, absolute cleanliness is essential, and cleaning should be regular and thorough.

They must then be blown through and properly lubricated before use.

9. **The electric-air system.**—The relatively low efficiency of pneumatic transmission and the relative convenience of air-operated tools, as compared with those driven directly by electric motors, for such purposes as chipping and coal-cutting, has resulted in the evolution of a combined system known as *electric air.*

In this system, power is carried efficiently by electric cables to electric motors carried on small trucks, which can be placed within a few feet of the site of the work. Each electric motor drives, through a belt or other reducing gear, a small compressor carried on the same truck.

No air receiver need be supplied in most cases; in fact an attempt is made to avoid the heat loss, due to cooling in a receiver, by supplying the air as hot as possible to the pneumatic tools, whose flexible hoses are short. Leakage losses are eliminated by using only one length of hose to each tool, with no couplings beyond those on the compressor and tool.

This method has not been very successful commercially, however, and is now seldom met with.

For Bibliography, see page 690.

CHAPTER XXXV

REFRIGERATING MACHINERY

164. *General principles*

1. Refrigeration is the process of lowering the temperature of a body below that of its surroundings, *i.e.* causing heat to travel from the body (which may be an ice-making tank, a cold store, or the air of a building) to a body at a higher temperature. To effect this it is necessary to expend energy, in accordance with the second law of thermodynamics, which states that heat will not travel from a cold body to a hot body by a purely self-acting process.

2. Excluding apparatus depending on the melting of ice (with or without the addition of salt, &c.), on chemical action, or on the evaporation of a volatile liquid supplied from an external source—apparatus which cannot be regarded as complete refrigerating machines, since they cannot operate continuously unless the active material is continually renewed—refrigerating machines can be regarded as reversed heat engines. In a heat engine, heat passes from a higher to a lower temperature, and in doing so a portion of it is converted into mechanical energy, through the medium of a working fluid. In a refrigerating machine, heat is forced to pass from a lower to a higher temperature, and mechanical energy (or additional heat) is applied to the working fluid to effect the transfer.

165. *Types of machines*

1. Refrigerating machines are of three principal types:—

   i. Compression machines.
   ii. Absorption machines.
   iii. Air-expansion machines.

The two latter types are practically obsolete (except for a special type of absorption machine for domestic refrigerators) owing to their low efficiency, but may still be met with, so are described briefly later on in this chapter.

2. All three types depend for the action on one or both of the following two principles:—

(*a*) *The latent heat principle.*—Every substance in passing from the liquid to the gaseous state absorbs heat, known as the Latent Heat of Evaporation, and vice versa, gives up latent heat on passing from gaseous to liquid state.

(*b*) *The expansion principle.*—When a gas expands without heat transmission, its temperature falls, and when it is compressed without heat transmission its temperature rises.

166. *Compression machines*

1. This is the type now almost universally employed. Pl. **130**, Fig. 1, shows the plant diagrammatically.

The plant consists essentially of a ***compressor*** (driven by external agency), a ***condenser***, an ***expansion valve***, and an ***evaporator***. These units are connected by piping and form a *closed circuit* in which a fluid known as the *refrigerant* circulates. This fluid is a gas at normal atmospheric temperatures and pressures, but can be liquefied by pressure at atmospheric temperature.

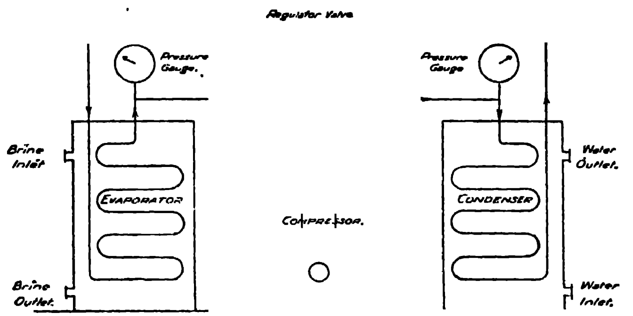
2. The cycle of operations is as follows :—

The refrigerant in the form of a wet gas at low pressure is sucked into the compressor and compressed, approximately adiabatically. Its temperature rises on compression and the refrigerant leaves the compressor as a dry gas at a comparatively high temperature and at a pressure which would be sufficient to liquefy it at a little above atmospheric temperature. The refrigerant then passes to the condenser, where it is cooled either by air or water to approximately atmospheric temperature. As it is brought down to this temperature it liquefies, giving up its latent heat of evaporation to the cooling agent. The refrigerant next passes through an *expansion valve* sometimes called the *regulator*, which is a throttle valve, provided with means of fine regulation, restricting the flow to a small orifice. Owing to the restricted flow, and the suction of the compressor, the pressure of the refrigerant is reduced, on passing through the expansion valve, below the pressure needed to liquefy it even at temperatures well below 0° C. The refrigerant therefore commences to evaporate, and in so doing to cool itself by absorption of latent heat to a temperature at which evaporation ceases ; during this cooling process it passes through the evaporator, which consists of coils either in contact with the air of a chamber which is to be cooled or immersed in a tank of brine which is to be cooled and used as an intermediary for cooling other objects. The refrigerant absorbs heat from the air or brine, evaporating as it does so, and finally passes out to the suction valve of the compressor as a wet gas at a low temperature and pressure, or possibly, if sufficient heat has been absorbed, as a dry gas.

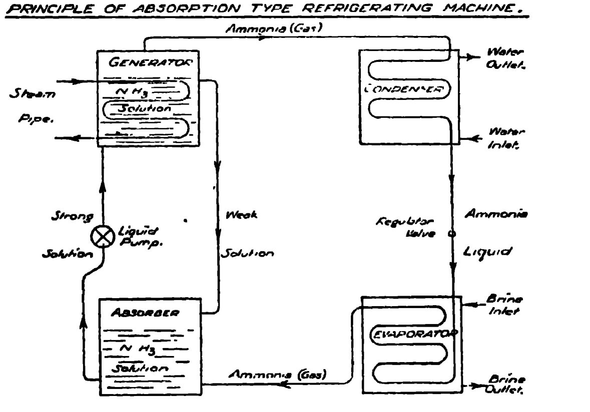
3. It is usually arranged that evaporation shall not be quite complete, a certain amount of liquid passing with the

PLATE 130.

PRINCIPLE OF COMPRESSION TYPE REFRIGERATING MACHINE.



PRINCIPLE OF ABSORPTION TYPE REFRIGERATING MACHINE.



gas into the compressor ; this helps to keep the pressures and temperatures in the compressor within reasonable limits, as the evaporation of the remaining liquid absorbs much of the heat of compression. Machines in which the gas is thus still mixed with liquid on reaching the compressor are said to work on the Wet Compression cycle. Dry compression avoids the danger of too much liquid in compressor head.

The entropy-temperature diagram for the cycle is shown on Pl. **131**, Fig. 1.

AB = evaporation at constant temperature.
BC = adiabatic compression.
CD = condensation at constant temperature.
DA = expansion through expansion valve.

The line AH represents the change of entropy necessary to convert *all* the liquid into vapour. The change AB occurs during evaporation and BH during compression.

The step DA is not reversible, but in the practice the loss is so small that an expansion cylinder which would make the cycle reversible is not warranted.

167. *Choice of refrigerant*

1. The number of fluids suitable for use as refrigerants is limited. The following conditions must be satisfied :—

(*a*) The refrigerant must be capable of being liquefied, at condenser temperature, by a pressure which can easily be obtained with a simple compressor.

(*b*) The refrigerant must not solidify at any temperature within the range of working, as this would lead to choking of valves, &c.

(*c*) It must have no corrosive effect on the metal of the machines.

2. The following properties are also desirable :—

(*a*) The vapour pressures at evaporator temperatures should be slightly above atmospheric. A pressure below atmospheric is liable to cause air leaks into the system and consequent troubles and low energy ratio. A high vapour pressure means high pressures throughout the system and consequently an expensive plant and greater liability to leakage.

(*b*) A high latent heat of evaporation—this enables greater refrigerating effect to be obtained from a given quantity of refrigerant.

(*c*) A critical temperature a long way above the condenser temperature. The nearer the critical temperature the lower the latent heat of evaporation and consequently the less the

To face p. 626]

ENTROPY TEMPERATURE DIAGRAM FOR REFRIGERATING MACHINE

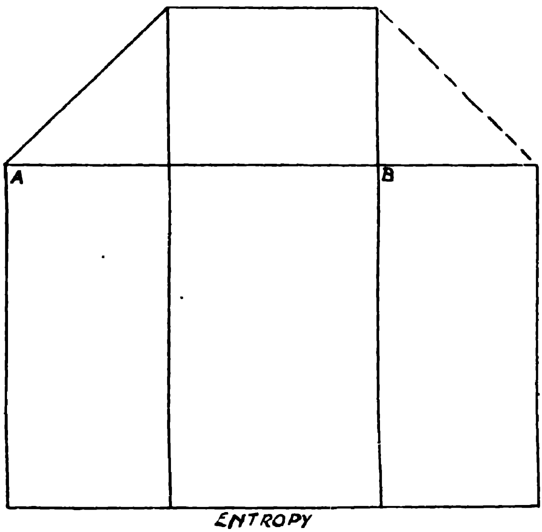


Fig. 1.

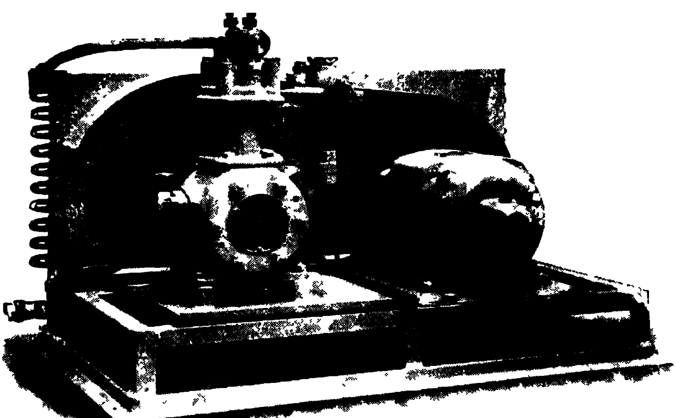


Fig. 2.

"HALLMARK" METHYL-CHLORIDE SELF-CONTAINED REFRIGERATING MACHINE UNIT

refrigerant effect. (N.B.—The critical temperature of a gas is the temperature above which it is impossible to liquefy it by pressure, however high.)

(*d*) Non-poisonous and have no tainting effect on foodstuffs if it escapes.

3. For practical purposes the choice of a refrigerant is restricted to ammonia, carbon dioxide, sulphur dioxide, and methyl chloride. Their principal properties are tabulated in Table **ZB**. *Anhydrous ammonia* gives the greatest energy ratio and has every advantage except (*d*) above. It is decidedly poisonous and will taint foodstuffs readily. With modern plant, properly maintained, leakages should be rare, and owing to the pungent smell are quickly detected. Ammonia corrodes brass and copper, but does not affect iron or steel.

4. **Carbon dioxide** is much used on board ship as it is non-poisonous and will not taint food; but it is generally unsuitable for military purposes, as the energy ratio is low, and owing to the very high pressure required, special attention is necessary. Moreover, in tropical climates the condenser temperature may exceed the critical temperature (88° F.), with consequent loss of efficiency and output, though this difficulty can be met by using a special cycle of operations (*see* Sec. **170,** para. 11).

For a given output, owing to the high pressure, CO_2 machines are small compared with ammonia machines, but very strong, heavy, and expensive.

5. **Sulphur dioxide** uses very low pressures—undesirably low, as they may fall below atmospheric. Leakage of air and water into the system causes the formation of highly corrosive acid. The gas is poisonous and offensive. It has the advantage that in the liquid state it is a lubricant, which makes it suitable for small automatic machines. Otherwise it is not to be recommended, and has now largely been displaced by methyl chloride, except for domestic refrigerators.

6. **Methyl chloride** machines have only recently been developed. They are usually small machines with automatic or semi-automatic control, for which duty methyl chloride is almost ideal. The pressures are low, but not too low; it is non-corrosive, but inflammable and somewhat poisonous. Energy ratios are good, but not equal to ammonia. It mixes with lubricating oil, thus avoiding troubles due to oil in the system.

7. **Ammonia machines** are recommended for outputs above 150 B.Th.U. per minute. For smaller duties methyl chloride machines with automatic control are suitable.

168. *Performance of refrigerating machines*

1. **Energy ratio.**—A refrigerating machine is a reversed heat engine and its performance is measured by the energy ratio :—

$$\frac{\text{Heat extracted}}{\text{Heat expelled to condenser} - \text{heat extracted from brine}}$$
$$= \frac{\text{Heat extracted}}{\text{Heat equivalent of work done in compression}}.$$

This can be shown to be equal to $\frac{T_1}{T_2 - T_1}$.

Where T_1 and T_2 are the absolute temperatures of the refrigerator at which heat is absorbed from the brine (or air of cold store) and rejected to the condenser cooling water respectively.

To effect heat transference T_1 must always be lower than the brine temperature and T_2 must always be higher than the condenser water temperature. The ratio $\frac{T_1}{T_2 - T_1}$ is, therefore, limited practically. Further, owing to mechanical and other losses, the actual energy ratio obtained in practice is considerably lower than the theoretical ratio. It may, however, in favourable conditions be as high as 12. A fairly normal figure is about 4.

It will be noted from the formula that the lower the temperature of the brine, &c., and the higher the temperature of the cooling water, the lower the energy ratio.

The energy ratio is frequently called the *Coefficient* (or *Factor*) *of Performance.*

It is better not to use the expression *efficiency* in this connection, since the energy ratio is *not* efficiency in the ordinary meaning of the term.

Consider the first set of figures in Table **ZC** on page 647.

$$T_1 = 30 + 459 = 489° \text{ F. absolute}$$
$$T_2 - T_1 = 55 - 30 = 25° \text{ F.}$$

$$\therefore \text{ the } \textit{theoretical energy ratio} = \frac{489}{25} = 19{\cdot}6$$

$$\text{also the } \textit{practical energy ratio} = \frac{150 \times 778}{0{\cdot}3 \times 33{,}000} = 11{\cdot}8.$$

2. **Output.**—This is usually measured in British Thermal Units per minute extracted from the brine or cold store.

The output of the machine is affected by the temperatures in the same way as the energy ratio, but not to the same extent, as the variations in energy ratio are partly compensated for by variations in the power required to drive. A higher condenser temperature gives reduced output and increased power to drive, and vice versa; a lower refrigerator temperature

gives reduced output, while the power to drive first rises to a maximum as the refrigerator temperature falls, and then falls with the temperature.

3. **Rating.**—It follows from the last paragraph that any attempt to give machines a rating based on their output is useless unless *standard conditions* are laid down on which the rating can be based. There are at present several standards and several methods of rating, as described below :—

(*a*) *American rating.*—This is commonly used commercially. The capacity of a machine is given in "tons of refrigeration," a ton of refrigeration being a refrigerating effect equal to the melting of one American ton (2,000 lb.) of ice per 24 hours. (This is equal to 200 British Thermal Units per minute.) The standard conditions are an inlet pressure (*i.e.* in the evaporator) corresponding to a saturation temperature of 5° F., and an outlet pressure (*i.e.* in the condenser) corresponding to a saturation temperature of 86° F.

This rating is applied to the compressor only, not to a complete plant.

It should be noted that a machine of one ton rating is not capable of making one ton of ice per 24 hours. Under normal conditions the output would be about 8 to 10 cwts.

(*b*) *International rating.*—The capacity is stated in kilogramme calories per hour when cooling brine from −2° to −5° C. with water entering the condenser at 10° C. and leaving it at 15° C. This rating is applied to the complete plant. (1 kilogram caloric equals 3·96 B.Th.U. = $\frac{1}{860}$ kWh.)

(*c*) *British rating.*—The unit is 1 kilogram calorie per second (238 B.Th.U. per minute), and the standard conditions are: brine cooled from 0° C. to −5° C. and cooling water raised from 15° C. to 20° C. (*N.B.*—Under usual conditions, this corresponds to evaporator temperature of approximately 14° F. and condenser temperature of approximately 74°, the figures used in Table **ZC**.)

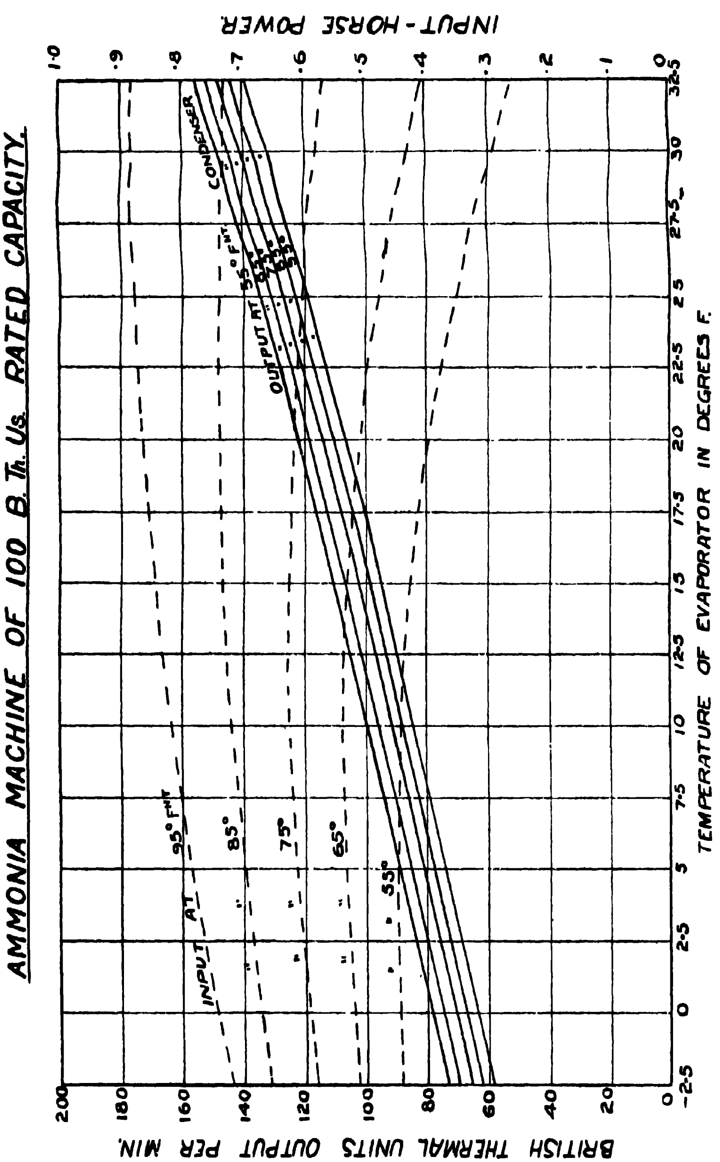
(*d*) *Rating by B.Th.U.*—The capacity is taken under the standard conditions for the British Rating, but is expressed in B.Th.U. per minute. This is probably the most convenient rating for calculations.

The curves in Pl. **132** and the figures in Table **ZC** are representative of small ammonia machines. Larger machines should have higher energy ratios. The effect of altering the temperature range should be carefully noted.

169. *Constructional details*

1. **Compressors.**—Compressors vary greatly in design. They may be single or multi-cylinder, and single or double-acting, and the design also depends on the refrigerant used.

PLATE 132.


AMMONIA MACHINE OF 100 B. Th. Us. RATED CAPACITY.
INPUT - HORSE POWER
TEMPERATURE OF EVAPORATOR IN DEGREES F.
BRITISH THERMAL UNITS OUTPUT PER MIN.
CONDENSER
OUTPUT AT 55° F.NT 65° 75° 85° 95°
INPUT AT 95° F.NT
85°
75°
65°
55°

Thus with ammonia the pressure range is normally about 25 to 125 lbs. per square inch, for which a simple compressor of normal construction is suitable, whereas with carbon dioxide the range is about 300 to 1,000 lbs. per square inch, for which a very strong construction and special means of preventing leakage of gas are necessary.

Pl. **133** shows a typical small ammonia compressor, single cylinder, single acting, with automatic spring-loaded valves. It should be noted that the crankshaft is provided with a packing gland ; the crankcase and cylinder jacket are maintained at suction pressure (being connected up to the suction side of the machine by the crankcase vent-pipe). This minimizes the loss of gas due to leakage past the piston, which is bound to occur to a certain extent. Any gas which leaks through is drawn off into the suction pipe. There is little likelihood of any escaping past the crankshaft packing gland, as the pressure difference is small and the packing can be made very efficient at this point. It also enables the oil to be blown out of the ammonia system into the crank case without losing any ammonia, while the jacketing of the cylinder with the cold gas of the suction side assists to keep down the temperature in the cylinder. Single-acting compressors sometimes have water-cooled heads, but this is not usual.

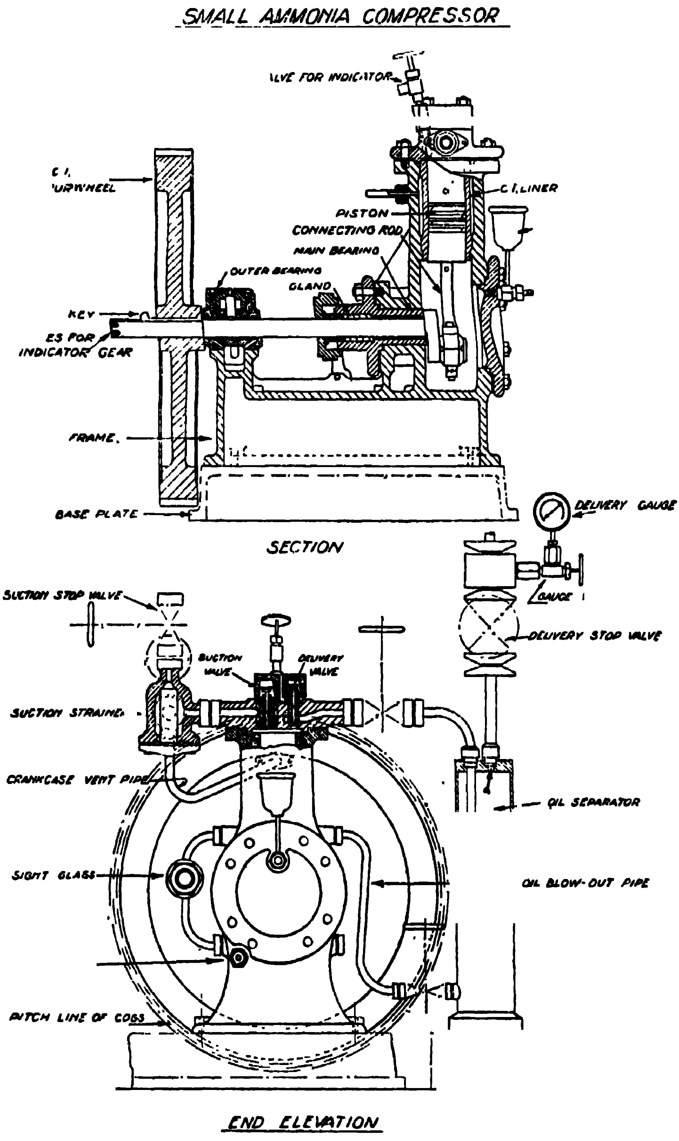
Single-stage compressors, as illustrated, are suitable for compression ratios up to about 6 to 1, which is sufficient for the temperature ranges usually dealt with. For very low temperatures it may be necessary to use two-stage compressors. These will seldom be met with in military service.

To obtain the maximum output and efficiency, the clearance volume of the compressor must be reduced to a minimum, especially with wet compression, but on the other hand when using wet compression a certain amount of clearance is essential for safety, as there is always a possibility of an excess of liquid refrigerant reaching the compressor ; if there is insufficient clearance this may blow off the cylinder head. Large compressors are usually provided with a safety device, such as a spring head, to avoid this possibility. Small compressors frequently depend on sufficient clearance volume as a safeguard.

A low piston speed has been usual in the past in machines with plate valves, chiefly dependent upon the relative area of the piston and the valves. The latter should be as large and light as possible. Higher speed machines with sleeve valves for direct drive by electric motors, or high-speed engines, are now being largely employed (*see* Sec. **161**).

2. **Oil separators.**—Referring again to Pl. **133**, it will be seen that the ammonia on leaving the delivery valve passes

PLATE 133.


SMALL AMMONIA COMPRESSOR
VALVE FOR INDICATOR
C.I. FLYWHEEL
C.I. LINER
PISTON
CONNECTING ROD
MAIN BEARING
OUTER BEARING
GLAND
KEY
ES FOR INDICATOR GEAR
FRAME.
BASE PLATE
SECTION
DELIVERY GAUGE
GAUGE
SUCTION STOP VALVE
DELIVERY STOP VALVE
SUCTION VALVE
DELIVERY VALVE
SUCTION STRAINER
CRANKCASE VENT PIPE
OIL SEPARATOR
SIGHT GLASS
OIL BLOW-OUT PIPE
PITCH LINE OF COGS
END ELEVATION

through an oil separator. A certain amount of oil is bound to work past the piston into the compressor cylinder, and is carried away in a finely divided state in the ammonia. If not previously removed, much of it will be deposited in the condenser, forming a film which will impede heat transference and seriously affect the efficiency. In the oil separator the particles of oil are carried to the bottom of the vessel by their momentum, while the gas passes out by the pipe at the top of the vessel. The separator is connected by a pipe, with stop-valve, to the crankcase. Every three or four hours, while the plant is running, the attendant should open the valve for a few seconds, when the pressure of the gas will drive the oil into the crankcase. A sight-glass on the crankcase enables the level to be checked. Splash lubrication is used in this case, and is adequate for small plants, with the low speeds used.

3. **CO_2 compressors.**—Both CO_2 and ammonia machines are made in a full range of sizes from about $\frac{1}{2}$ ton to 200 tons rating.

The heavy construction of CO_2 machines will be noted; the cylinders are machined from solid billets of steel. A special high-pressure packing gland is used on the piston-rod, and crosshead construction is used to relieve the packing of the heavy side thrusts, which would cause leakage.

4. **Methyl chloride compressors.**—Pl. **131**, Fig. 2, shows a small methyl chloride machine, complete with air-cooled condenser and electric motor. A machine of this type, which is usually provided with automatic control, is very suitable for small meat stores, &c., up to about 500 cu. ft. in temperate climates. About $1\frac{1}{4}$ B.H.P. would be required for this duty, the machine running intermittently.

170. *Condensers*

1. The condensers used for refrigerating machinery do not differ in principle from steam condensers, being simply heat exchangers, by means of which the heat generated by compression and the latent heat of evaporation are transferred from the refrigerant to the cooling water (or air), thus liquefying the refrigerant. In all types of refrigerating condensers the refrigerant passes through a coil or series of pipes, while cold water or air passes over the surface of the pipes. To effect heat transference as rapidly as possible, the velocity of both the refrigerant and the water should be as high as possible. To bring the final temperature of the refrigerant as low as possible, the contra-flow principle is normally adopted—*i.e.* the refrigerant and the water enter at

opposite ends of the condenser, so that the coldest water meets the coldest refrigerant just before it leaves the condenser, the hot refrigerant entering the condenser, being first cooled by water which has already been warmed somewhat.

A reference to the formula $\frac{T_1}{T_2 - T_1}$ already quoted shows that the energy ratio of the whole plant depends very largely on the condenser.

Condensers are of three principal types :—

2. **Submerged condenser.**—This consists of a coil of piping through which the refrigerant passes, immersed in a vessel through which water is passed. The movement of the water being slow, this type requires a greater surface than other types, so is seldom used except for small plants.

3. **Open condensers** (Pl. **134**, Fig. 1).—In this type the refrigerant passes through coils of pipe arranged in the form of a vertical screen, and water is allowed to flow over the surface of the pipes from a perforated pipe at the top. The whole is placed in the open air, but screened from sun and from high wind (which might blow the water off the pipes), and stands over a tank in which the water is collected. If the exposed area of piping is large enough, and the air reasonably dry, the water will be cooled by evaporation as fast as it takes up heat from the pipes, and will therefore maintain a steady temperature. In this case the same water can be used repeatedly, being circulated by means of a pump with a little added to make up for evaporation. The contra-flow principle is not applied in this case, the water being at practically the same temperature throughout ; refrigerant and water both enter at the top of the condenser.

Given a fairly dry atmosphere and therefore rapid evaporation, this type is most efficient, and is economical of water. It is the type generally used for large installations.

This type of condenser acts as a cooling tower as well as a condenser, and its size is usually fixed by the requirements of the former function. If an ample supply of cold water is available, the condenser may be made much smaller. In this case, as the water rises in temperature as it passes over the coils, a contra-flow action is necessary ; the refrigerant is therefore admitted at the bottom of the condenser. The liquefied refrigerant is usually drawn off at several points in order to maintain the temperature difference.

4. **Double-pipe condenser.**—This type consists of two concentric pipes, either bent into a " zig-zag " or built up from a number of straight lengths with specially designed connecting pieces. *See* Pl. **134**, Figs. 2 and 3.

The refrigerant passes through the inner pipe, entering

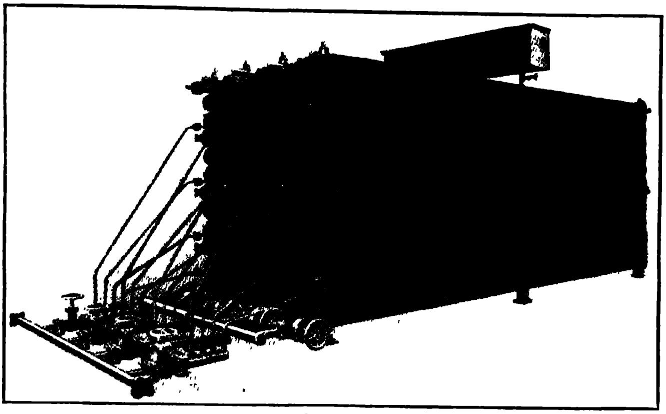


Fig. 1.
EVAPORATIVE TYPE AMMONIA CONDENSER. (HASLAM.)

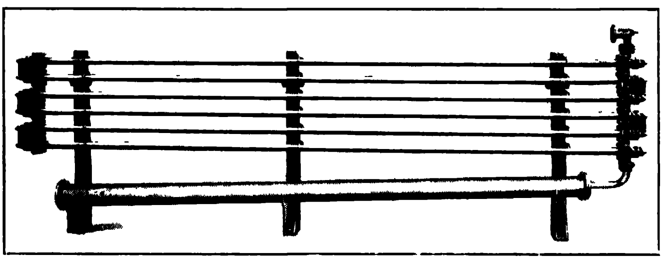


Fig. 2.
LIGHTFOOT DOUBLE-TUBE TYPE AMMONIA CONDENSER WITH LIQUID RECEIVER

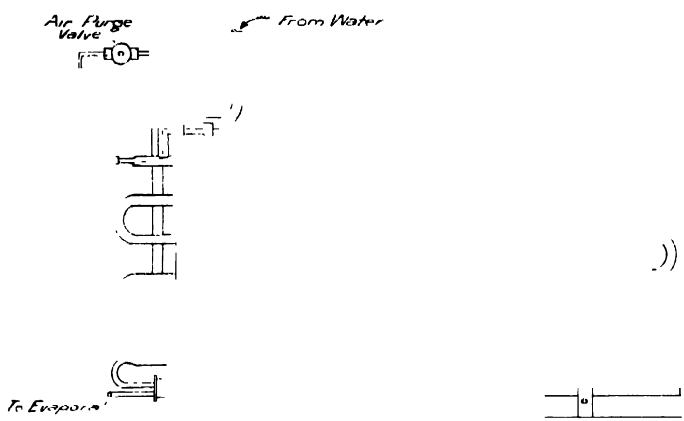


Fig. 3.
TYPE OF DOUBLE TUBE CONDENSER

[*Fig.* 1.—*Permission of Messrs. Haslam & Newton, Ltd.*]
[*Fig.* 2.—*Permission of Lightfoot Refrigeration Co., Ltd.*]

at the top; the water through the annular space entering at the bottom.

The built-up pattern is easier to clean out, and should be used if there is likely to be much deposit from the water, but the large number of joints is a disadvantage.

This type of condenser is very efficient, owing to the rapid flow both of water and refrigerant; it is compact and easily adapted to cramped positions, and there is no water-splashing. It is much used for small installations where water is plentiful and cheap.

5. **Sizes of condensers.**—The following areas of cooling surfaces are required per 100 B.Th.U. refrigerative capacity under standard temperature conditions :—

Submerged condensers	15 sq. ft.
Double-pipe condensers	4 sq. ft.
Open, evaporative type	12 sq. ft. or more.
Open, flooded type	5 sq. ft.

It should be noted, however, that the size depends on the duty of the plant, not on its rating; for instance, if the temperatures required in the evaporator are not as low as the standard values, the output of the plant will be increased and a larger condenser will be needed. If the evaporator temperature is 30° F. the above areas should be doubled. This will be clear from Pl. **132**.

6. **Water required.**—With open type condensers, a minimum of half a gallon per minute for every foot run of piping should be used. If the water is recirculated, the flow should be increased to about 2 gallons per minute, as this helps evaporation.

With a submerged or double-pipe condenser, the quantity depends on the permissible rise of temperature, which again depends on the inlet water temperature and the output required from a given power available. The condenser temperature of the refrigerant will be approximately a constant amount above the outlet water temperature. The water will be required to absorb the heat taken up by the evaporator, plus the heat equivalent of the work done in the compressor, less a certain amount of loss by radiation, &c. The amount necessary can therefore be calculated.

For example, taking again the first set of figures in Table ZC, the refrigerant extracts 150 B.Th.U. per minute from the brine and receives

$$\frac{0{\cdot}3 \times 33{,}000}{778} \times 0{\cdot}6 = 7{\cdot}6 \text{ B.Th.U.}$$

in the compressor (assuming 40 per cent. of B.H.P. input goes

in radiation from surface of compressor and to compressor cooling water).

Therefore, neglecting heat exchanges between connecting pipes and air, the condenser cooling water removes $150 + 7{\cdot}6 = 157{\cdot}6$ B.Th.U. per minute. Assuming a 10° F. rise in temperature of cooling water, it must circulate at the minimum rate of $\frac{157{\cdot}6 \times 60}{10 \times 10} = 94{\cdot}56$ (say 100 galls./hour).

7. **Air-cooled condensers.**—For very small plants, such as domestic refrigerators, air-cooled condensers are sometimes used. They are similar to motor-car radiators in principle, but, of course, constructed to withstand the high pressure used. A fan is usually provided. They are less efficient than water condensers, but may be very useful in many situations where water is scarce.

8. **Materials.**—For ammonia plant, steel piping must be used. For CO_2 plant, copper piping is used, owing to its better conductivity.

9. **Liquid receivers.**—A liquid receiver usually forms part of the condenser side of the circuit. It is a vessel, which may form part of the condenser and in any case is connected to the condenser outlet, large enough to contain the whole charge of refrigerant in the liquid state. It provides space for an excess of refrigerant above the normal working charge, thus forming a reserve to make up for leakage and avoiding the necessity of adding fresh refrigerant at short intervals. It also provides a space into which most of the charge can be pumped and sealed up by shutting the stop valves, in order to allow the plant to be opened up for repairs without loss of the charge. It is often omitted with evaporative condensers, as these are large enough to provide all the space needed.

10. **Liquid coolers.**—With evaporative condensers, as the water flowing over the condenser is higher in temperature than the make-up water, the liquid refrigerant is often further cooled in a liquid cooler—which may be similar to a double-pipe condenser—through which the cold make-up water is circulated. The more the liquid can be cooled before evaporation, the less evaporation is required for self-cooling after passing the regulator, and the more liquid is therefore available for evaporation in the refrigerator. This is especially the case with CO_2.

With double-pipe, submerged, or flooded condensers, the contra-flow arrangement of the condenser ensures maximum cooling of the liquid.

11. **Intermediate liquid coolers for CO_2.**—CO_2 machines, especially if required to work in the tropics, are

often fitted with another form of liquid cooler, in which the expansion of part of the refrigerant to a pressure intermediate between the condenser and evaporator pressures is used to cool the remainder of the liquid to about 20° F. By this means the output of the machine is increased by about 20 per cent. and the CO_2 can be brought down below its critical temperature, even when the condenser temperature is unduly high. CO_2 evaporated in the pre-cooler is admitted to the compressor at the end of the suction stroke through special ports.

For details of CO_2 liquid coolers, the makers' handbooks should be studied.

171. *Evaporators*

1. In the evaporator (sometimes called the refrigerator) the action is the reverse of that in the condenser, the liquid refrigerant evaporating, under the low pressure maintained by the suction of the compressor, and absorbing heat from its surroundings. Evaporators are of two principal types, (*a*) direct expansion evaporators and (*b*) brine coolers. Direct expansion evaporators are as a rule only used for air cooling. The air of the cold store is circulated over coils of piping in which the refrigerant evaporates. To keep the pipes free from frost (which acts like a lagging and impedes heat transfer) when dealing with temperatures below freezing point, the coils stand over a brine tank and brine is circulated over the pipes.

Direct expansion is also used in some cases for ice-making, milk cooling, &c. The designs depend on requirements, and are outside the scope of this book.

2. Brine coolers employ brine as a medium for transferring heat from the object to be cooled to the refrigerant. In general, they are similar in design to condensers, the brine replacing the cooling water. They may be submerged, double-pipe or open flooded. Detail designs depend on application, as before.

The brine used is usually a solution of calcium chloride, 4 lbs. per gallon, which is cheap, has a freezing point of —20° F., is non-corrosive and leaves no deposit. Sodium chloride (*i.e.* common salt) brine can be used, but, being much less soluble, it is apt to crystallize out at low temperatures, and its freezing point is higher. Moreover, it has a corrosive effect on steel unless a little caustic soda is added.

A minimum of 12 square feet of pipe surface per ton of refrigeration is required for double-pipe evaporators, and at least double this surface area for other types.

The brine system is less efficient than the direct expansion system as the double transfer of heat requires a lower evaporator temperature. It has many advantages, however; the brine acts as a "reservoir of cold," thus allowing the compressor to be shut down for considerable periods before a serious rise in temperature takes place. The brine can also be circulated where required and controlled in a number of circuits more easily and with less danger than the refrigerant can.

172. *Accessories*

1. **Stop-valves.**—Pl. **135**, Fig. 1, shows a typical ammonia stop-valve, which is usually made of semi-steel or high grade cast-iron. The valve discs have white metal seatings, and a seating is provided on the upper side to seal the valve when in the open position, enabling the spindle to be repacked without loss of ammonia. CO_2 valves are usually machined from solid billets of mild steel.

Valve spindle should be of rustless steel.

2. **Regulator.**—This valve (Pl. **135**, Fig. 2) requires accurate adjustment with a small opening to give the best results. It is therefore made with a fine thread, and the spindle has a tapered end extending through the valve opening. The hand-wheel is provided with a pointer and index to enable the correct position, once settled, to be found at once. It should not be used as a stop-valve; a stop-valve should adjoin it on the condenser side (known as the liquid stop-valve).

3. **Piping and joints.**—For ammonia machines, wrought iron piping is suitable. A typical joint for ammonia piping is shown in Pl. **135**, Fig. 3. The flanges are screwed on to the pipes, one pipe being recessed in the flange and the other projecting. A metal packing ring—aluminium may be used—is placed between the pipe ends, which are accurately faced up, and the flanges drawn together by the bolts.

For CO_2 machines, special hydraulic piping is used with heavy flanges and copper jointing rings.

4. **Pressure gauges** should be fitted on the suction and delivery pipes of the compressor; besides the ordinary pressure graduations, these gauges usually have an outer scale of temperatures. These temperatures represent the evaporation and liquefaction temperatures of the refrigerant at the corresponding pressures, and since the pressure in either side of the system is approximately the same throughout, the temperature indicated by the gauge at any moment is the temperature at which the refrigerant is condensing or evaporating. This is the temperature at which most of the heat transference takes place,

PLATE 135.

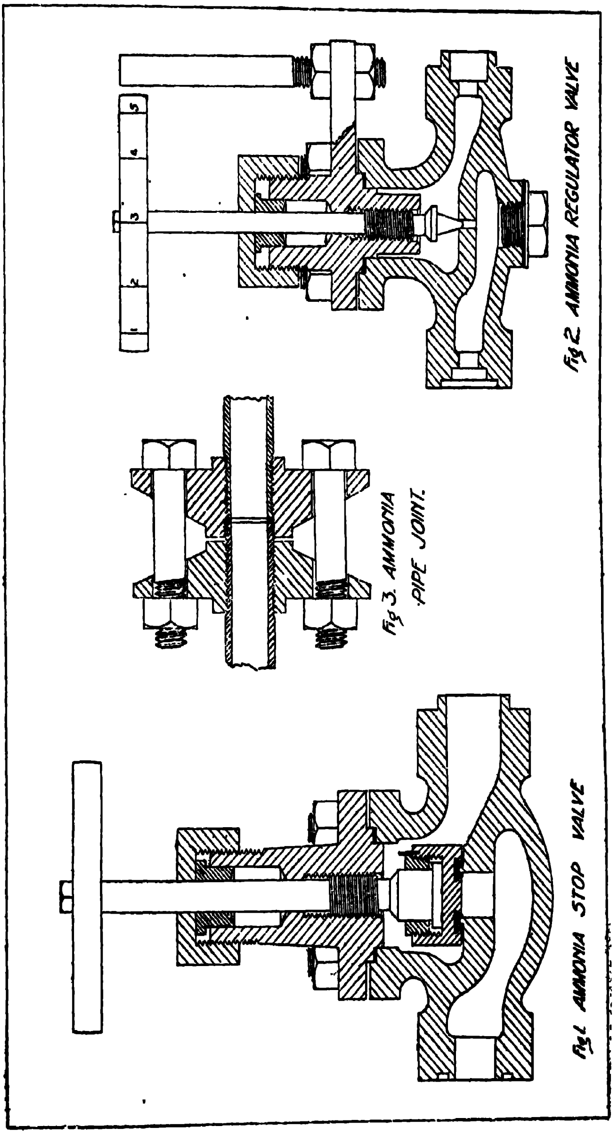


Fig 2 AMMONIA REGULATOR VALVE
Fig 3. AMMONIA PIPE JOINT.
Fig 1 AMMONIA STOP VALVE

and may fairly be taken as the average temperature of heat transference. The gauge temperatures (converted to absolute scale), therefore, may be used in the formula $\frac{T_1}{T_2 - T_1}$.

It should be noted that the gauge temperatures are evaporation or liquefaction temperatures *deduced* from the pressures, and not actually measured at the gauge points.

They give the temperatures accurately only when the refrigerant is a wet gas.

173. *Absorption machines*

1. In an absorption type refrigerating machine the external energy is applied in the form of heat, which produces a high pressure by driving off the refrigerant from a liquid in which it has been dissolved. The affinity of the cold liquid for the refrigerant is used to produce a suction effect.

The refrigerant may be water, which can be absorbed by sulphuric acid, or ammonia absorbed by water.

The former type, although it was one of the earliest ice-making machines, is only of interest as a laboratory experiment. The ammonia absorption machine of large or medium size is also obsolete, owing to its very low energy ratio (seldom more than 1). Pl. **130**, Fig. 2, shows the principle diagrammatically.

The generator contains strong ammonia solution, which is heated by steam pipes, and gives off ammonia gas at a fairly high pressure and temperature. The gas is freed from water by various devices and passes to the condenser, thence by the regulator valve to the evaporator (all these parts of the circuit being similar to those used with a compression plant). The absorber contains water, or rather weak solution, which has been passed into it from the generator and water-separating devices; this water is cooled before entering the absorber, and having a violent affinity for ammonia, it absorbs it as it comes from the evaporator, and so keeps down the pressure. The strong solution is then pumped into the generator and the cycle repeated. The small circulating pump is the only part requiring mechanical power.

2. **The Electrolux unit.**—A form of ammonia absorption machine on a small scale, which has been successfully developed in recent years, is the Electrolux domestic refrigerator. The action is complicated and will not be detailed here, but depends on the mixture of hydrogen with the ammonia in the low pressure side of the circuit. By Dalton's law of gaseous pressures, the total pressure exerted by a mixture of gases is the sum of the pressures which would be exerted

by each gas separately. The total pressure can thus be maintained the same throughout the circuit, although the ammonia pressure is reduced on the low-pressure side to produce the refrigerating effect. The circulating pump is thus eliminated, and circulation can be maintained by convection aided only by the bubbling action of the ammonia as it boils in a tube. The source of heat may be an electrical element, a gas flame or an oil lamp, and a supply of cold water is also necessary.

The Electrolux unit has a very low energy ratio; exact figures are not available, but apparently an output of about 300 B.Th.U. per hour is obtained from a constant input of 250 watts—an energy ratio of about 0·36. For such small units, this does not greatly matter, and it has the advantage of possessing no moving parts, and can, moreover, also run on gas or oil (gas consumption about 3½ cubic feet per hour).

174. *Air-expansion machines*

1. This type is also obsolete, owing to its very low energy ratio—about 0·5 being normal. The principle of operation is as follows:—

Air is drawn from the atmosphere and compressed to about 65 lb. per square inch, causing its temperature to rise.

It is then passed through a cooler, similar to a condenser, by which it is reduced to about 20° above the atmospheric temperature.

It is then allowed to expand in a cylinder against a piston, doing work which assists to drive the compressor—providing as a rule about half the power required for this purpose. In expanding, it cools to a very low temperature.

The air is then passed through a snow-box, in which the moisture, which will have condensed into snow, is trapped. The dry cold air can then be circulated through stores, magazines, &c.

The compressor, expander, and an engine to supply the balance of the power required to drive the compressor, normally work on a common crankshaft.

Where the energy ratio is of little importance, this system has certain advantages of simplicity and absence of offensive gases, but will seldom be met with now.

175. *Operation of plant*

1. The following notes refer particularly to ammonia plant, which will be most commonly met with, but apply generally to other types. They should be read in conjunction with the makers' handbooks.

2. **Testing and charging new plant.**—The plant having been erected according to the makers' drawings, must be tested for gas-tightness before charging with ammonia. Close the suction stop-valve and break the joint between this valve and the cylinder head, or otherwise open the suction of the compressor to the air; open regulator, delivery and liquid stop-valves. See that oil level in compressor is correct and start compressor, which will then pump air into the system. Pump up to about 80 lb., remake joint with cylinder head, and open suction stop-valve. It is dangerous to pump air to higher pressures in one stage without water-cooling. The delivery temperature should be watched, and the machine stopped to cool at intervals if it gets unduly hot. After an initial fall of pressure, due to cooling of the compressed air, the pressure should become steady. Leave for about 24 hours. If a continued fall of pressure occurs, examine all joints for leaks, which may be located with the help of soapy water, which will show up the leaks by bubbling.

3. When all leakage has been stopped, the plant may be charged with ammonia. First the air must be pumped out. Break the joint between the delivery stop-valve and the cylinder head, or otherwise open to the air, and when the excess air has escaped, close the valve, leaving suction stop-valve, liquid stop-valve and regulator open. Start compressor and run until the pressure will fall no further, then make the joint again. Open both suction and delivery stop-valves and close regulator stop-valve. Suspend an ammonia bottle from a spring balance, note the weight, and connect by a long pipe to the charging valve, which will be found on the suction pipe. Open the charging valve fully and the valve on the ammonia bottle very slightly. When the suction gauge indicates about 50 lb. pressure, start the compressor and also turn on the condenser cooling water. If the suction pressure falls to a vacuum again, the compressor should be stopped temporarily.

The weight of ammonia required will be stated by the makers, and charging should be continued until this weight (as shown by the reduction in the weight indicated on the spring balance) has been put in, when first the valve on the ammonia bottle and then the charging valve should be shut and the regulator adjusted to keep the delivery down to the normal temperature. The machine should then be run for a few hours and then purged of air.

4. **Air purging.**—After charging, a certain amount of air will still be trapped in the system. This has a very bad effect on the efficiency of the plant, and must, therefore, be eliminated. After running for a few hours, the plant should be shut down, and the condenser water kept running for a

few hours. Most of the ammonia will then liquefy in the condenser, and the air will accumulate above it and may be passed out through the purge-valve, which is situated at the highest point of the piping leading from the condenser, or at the top of the condenser itself. A length of piping should be connected to this valve and led into a bucket of water. If the valve is then slightly opened, the air will appear as bubbles, whereas the ammonia, being very soluble, will be absorbed, making a crackling sound. Continue until the bubbles cease. The machine should then be run again and the process repeated until all the air is eliminated. (For indications of air in system, *see* Sec. **176.**)

5. **Starting and running.**—The following sequence should be observed :—

i. Start condenser water flowing ($\frac{1}{4}$ to $\frac{1}{2}$ hour before starting machine).

ii. See that oil level is correct and all lubricators filled.

iii. See that pressure gauge valves are open.

iv. Open delivery stop-valve.

v. Bar machine round for half a revolution to ensure that all is free.

vi. Start machine.

vii. Open liquid stop-valve.

viii. Open suction stop-valve very slowly. If opened too quickly, the compressor may be swamped with liquid, causing knocking and possibly damage ; the presence of liquid is shown by the delivery going cold when the valve is opened. The valve should not be opened further until the delivery begins to warm up.

ix. In single-acting compressors, with crankcase at suction pressure, the connection to the crankcase (crankcase pump-out valve) should now be opened very slightly.

x. The proper running position of the regulator will be found by experience. If the compressor delivery warms up rapidly, the regulator should be opened further, and vice versa. The delivery should be about as warm as the hand can bear, close up to the machine delivery valve. While running, the delivery temperature should be watched and the regulator adjusted accordingly.

xi. Watch oil level in crankcase and in oil separator, and when necessary, blow out the latter into the crankcase. In some cases this may be necessary every three or four hours. It is important that excess of oil should not be allowed to accumulate in the separator, as it may be carried into the condenser, causing serious difficulties.

xii. Watch the temperature shown by the pressure gauges and by the condenser and brine-tank thermometers. While running, the condenser gauge should show about 12° to 15° F. above condenser water inlet temperature, and the evaporator gauge about 10° to 12° F. below the brine temperature (or 15° to 20° F. below temperature of air in cold stores, if direct expansion is used). These temperature differences will vary with different plants, but should be fairly constant with any one plant; any considerable variation from normal indicates something wrong. (*See* Sec. **176.**)

6. **Shutting down.**—
   - i. Close liquid stop-valve.
   - ii. Close suction stop-valve.
   - iii. Stop machine.
   - iv. Close crankcase pump-out valve.
   - v. Close delivery stop-valve.
   - vi. Turn off condenser water.

176. *Faults in running*

1. For purely mechanical faults the makers' handbooks should be consulted, as diagnosis and treatment will vary with different machines. The causes of trouble dealt with below are common to most machines.

2. **Air in system.**—This causes a great loss of efficiency. The symptoms are (*a*) condenser gauge too high, (*b*) liquid temperature on leaving condenser too high, (*c*) machine runs hot unless regulator is opened more than usual, (*d*) when machine is at rest and condenser water has been circulating some time, the condenser gauge should show the same temperature as the circulating water; if it reads more than 5° F. higher, there is almost certainly air in the system. The method of purging has already been described.

3. **Oil in system.**—This may be caused by neglecting to blow out the separator, or by using unsuitable oil, which may vaporize in the compressor. The first symptom is usually partial choking of the regulator, which requires to be opened farther for a short time, and then clears again and requires to be closed; this has to be repeated frequently, and steady running is impossible.

At the same time the oil collects in the condenser and evaporator, forming an insulating film, and greatly reducing efficiency and output.

Small quantities of oil can usually be worked out of the system, but if it is allowed to accumulate, it may be necessary to clear the condenser and evaporator of gas, and blow out with hot air, or with steam followed by hot air to remove the moisture.

With methyl chloride machines, a certain amount of oil can circulate in the system without ill effects, as it mixes with the refrigerant and does not settle in a film or choke the regulator.

4. **Shortage of ammonia.**—The symptoms are :—
   (*a*) Compressor delivery too hot.
   (*b*) Condenser gauge low (compared with inlet water temperature).
   (*c*) Efficiency and output low.

5. **Overcharge of ammonia.**—This is unlikely and has not the bad effect of an undercharge, but increases the power required to drive the compressor. The other symptoms are :—
   (*a*) Condenser gauge high.
   (*b*) Compressor delivery too cold.

6. **Water in system.**—This gives little trouble with ammonia, as it forms a non-freezing solution, but with carbon dioxide water may cause trouble by freezing in the regulator valve or the evaporator. It can be extracted by passing the charge through a drier containing calcium chloride.

7. **Leakages.**—Leakages of ammonia are immediately obvious owing to the very pungent smell. If there is any difficulty in locating the leak exactly, burning sulphur will show the position by the formation of dense white fumes. Carbon dioxide is more difficult to detect ; if leakages are suspected, go over all joints with soapy water.

177. *General*

1. **Lubricating oil.**—The service oil for refrigerating compressors is Oil M. 60—" Light non-freezing mineral lubricant for refrigerating plant," but in some cases oil M.80 is better. One of these two oils should be suitable for any machine likely to be met with in the service. In case of doubt the makers should be consulted ; it is essential that suitable oil should be used.

Proprietary oils suitable for most machines are Gargoyle Arctic "C," A.II. Refrigerator Oil (Shell-Mex), Castrol Refrigerator Oil, and Zerolin (specially prepared for Lightfoot machines).

The specification given by Messrs. J. & E. Hall for oil for their machines is :—

Specific gravity 0·915 to 0·925.
Flash point (closed test) 325° F. to 335° F.
Freezing point —30° F. to —35° F.
Viscosity at 70° F. (Redwood No. 1) 350 secs.

The W.D. specification does not mention freezing point, but requires a special test of fluidity at —5° C.

2. **Refrigerants.**—Anhydrous ammonia and carbon dioxide may be purchased in liquid form, compressed in steel bottles of various sizes, containing from 30 lb. to 100 lb. as a rule. Anhydrous ammonia is also supplied by the R.A.O.D.

3. **Ammonia poisoning.**—Ammonia is a dangerous and painful poison, and, besides causing suffocation, may attack the eyes and burn the skin. A sponge soaked in water held over the mouth and nose will afford sufficient protection to enable one to enter a room full of the gas to pull out a person, who is overcome.

Weak vinegar and water should be given as an antidote. Eyes should be bathed with boric acid and skin burns treated with carron oil.

For Bibliography, see page 690.

TABLE ZB.—*Properties of refrigerants*

Refrigerant.	Anhydrous ammonia (NH_3).	Carbon dioxide (CO_2).	Sulphur dioxide (SO_2).	Methyl chloride (CH_3Cl).
Critical temperature	266° F.	88° F.	313° F.	289° F.
Vapour pressure (gauge) at 14° F.	27·5 lbs. per sq. in.	381 lbs. per sq. in.	zero	10·7 lbs. per sq. in.
„ „ „ „ 74° F.	123 lbs. per sq. in.	918 lbs. per sq. in.	38·8 lbs. per sq. in.	64 lbs. per sq. in.
Latent heat at 14° F.	558	116	169	177
„ „ „ 74° F.	505	52	154	166
Specific heat of liquid at 14° F.	1·1	0·74	0·36	0·47
„ „ „ „ 74° F.	1·1	1·8	0·36	0·47
Overall energy ratio normally obtained ..	4·0	2·5	3·5	3·5
Swept volume of compressor per minute per 100 B.Th.U. rating	3 cu. ft.	9·5 cu. ft.	8·0 cu. ft.	6·0 cu. ft.

TABLE ZC.—*Performance under varying conditions*

These results were obtained with an ammonia plant of 100 B.Th.U. per minute rating (*see* Pl. 132).

Evaporator temperature T_1	30° F.	30° F.	9° F.	9° F.
Condenser temperature T_2	55° F.	95° F.	55° F.	95° F.
Output (B.Th.U. per minute)	150	130	100	80
B.H.P.	0·3	0·9	0·45	0·80
Energy ratio	11·8	3·4	5·2	2·5
Theoretical possible energy ratio $\frac{T_1}{T_2-T_1}$ ..	19·6	7·6	10·0	5·5

APPENDIX I

Standard screw threads and tapping sizes

British standard, Whitworth			British standard, fine			British standard, pipe			British Association				American standard (Seller's)			International standard (metric)		
Full diameter of bolt	Threads per in.	Size of tapping hole	Full diameter of bolt	Threads per in.	Size of tapping hole	Nominal bore of tube	Full diameter of thread	Threads per in.	Designating No.	Full diameter (approx.)	Threads per in.	Size of tapping hole	Full diameter of bolt	Threads per in.	Size of tapping hole	Diameter of bolt	Pitch	Approximate threads per in.
In.	No.	In.	In.	No.	In.	In.	In.	No.		In.	No.	In.	In.	No.	In.	mm.	mm.	No.
1/32	*150*	*0·032*	7/32	28	0·1751	1/8	0·383	28	25	0·010	363	0·007	1/4	20	3/16	3	0·55	46·2
1/16	*60*	*3/64*	1/4	26	0·2027	1/4	0·518	19	24	0·011	317	0·008	5/16	18	1/4	3·5	0·55	46·2
3/32	*48*	*5/64*	9/32	26	0·2340	3/8	0·656	19	23	0·013	285	0·009	3/8	16	19/64	4	0·7	36·3
1/8	*40*	*3/32*	5/16	22	0·2563	1/2	0·825	14	22	0·015	259	0·011	7/16	14	23/64	4·5	0·7	36·3
5/32	*32*	*1/8*	3/8	20	0·3130	5/8	0·902	14	21	0·017	231	0·012	1/2	13	13/32	5	0·85	29·9
3/16	*24*	*9/64*	7/16	18	0·3684	3/4	1·041	14	20	0·019	212	0·014	9/16	12	15/32	6	1·0	25·4
7/32	*24*	*11/64*	1/2	16	0·4220	7/8	1·189	14	19	0·021	181	0·015	5/8	11	33/64	7	1·0	25·4
1/4	20	3/16	9/16	16	0·4845	1	1·309	11	18	0·024	169	0·018	3/4	10	5/8	8	1·25	20·3
5/16	18	1/4	5/8	14	0·5355	1¼	1·650	11	17	0·028	149	0·021	7/8	9	47/64	9	1·25	20·3
3/8	16	19/64	11/16	14	0·5980	1½	1·882	11	16	0·031	134	0·023	1	8	27/32	10	1·5	16·9
7/16	14	23/64	3/4	12	0·6453	1¾	2·116	11	15	0·035	121	0·026	1⅛	7	61/64	11	1·5	16·9
1/2	12	13/32	13/16	12	0·7078	2	2·347	11	14	0·039	110	0·029	1¼	7	1 5/64	12	1·75	14·5
9/16	12	15/32	7/8	11	0·7606	2¼	2·587	11	13	0·047	101	0·035	1⅜	6	1 11/64	14	2·0	12·7
5/8	11	33/64	1	10	0·8719	2½	2·960	11	12	0·051	90·7	0·039	1½	6	1 19/64	16	2·0	12·7
11/16	11	37/64	1⅛	9	0·9827	2¾	3·210	11	11	0·059	81·9	0·046	1⅝	5½	1 25/64	18	2·5	10·15
3/4	10	5/8	1¼	9	1·1077	3	3·460	11	10	0·067	72·6	0·053	1¾	5	1½	20	2·5	10·15
13/16	10	11/16	1⅜	8	1·2149	3¼	3·700	11	9	0·075	65·1	0·060	1⅞	5	1⅝	22	2·5	10·15
7/8	9	47/64	1½	8	1·3399	3½	3·950	11	8	0·087	59·1	0·070	2	4½	1 23/32	24	3·0	8·47

15/16	9	51/64	1⅝	8	1·4649	3¼	4·200	11	7	0·098	52·9	0·079	2¼	4½	1 31/32	27	3·0	8·47
1	8	27/32	1¾	7	1·5670	4	4·450	11	6	0·110	47·9	0·089	2½	4	2 3/16	30	3·5	7·26
1⅛	7	61/64	2	7	1·8170	4½	4·950	11	5	0·126	43·0	0·102	2¾	4	2 7/16	33	3·5	7·26
1¼	7	1 1/16	2¼	6	2·0366	5	5·450	11	4	0·142	38·5	0·115	3	3½	2 41/64	36	4·0	6·35
1⅜	6	1 11/64	2½	6	2·2866	5½	5·950	11	3	0·161	34·8	0·130	3¼	3½	2 51/64	39	4·0	6·35
1½	6	1 19/64	2¾	6	2·5366	6	6·450	11	2	0·185	31·4	0·150	3½	3¼	3 7/64	42	4·5	5·64
1⅝	5	1⅜	3	5	2·7439	7	7·450	10	1	0·209	28·2	0·169	3¾	3	3 21/64	45	4·5	5·64
1¾	5	1½				8	8·45	10	0	0·236	25·4	0·191	4	3	3 37/64	48	5·0	5·08
1⅞	4½	1 19/32				9	9·45	10					4¼	2⅞	3 13/16	52	5·0	5·08
2	4½	1 23/32	Cycle Engineers Inst.			10	10·45	10					4½	2¾	4 1/32	56	5·5	4·62
2⅛	4½	1 27/32				11	11·45	8					4¾	2⅝	4 17/64	60	5·5	4·62
2¼	4	1 15/16		Std.	Thread	12	12·45	8					5	2½	4 31/64	64	6·0	4·23
2⅜	4	2 1/16				13	13·68	8					5¼	2½	4 47/64	68	6·0	4·23
2½	4	2 3/16	17 S.W.G.	62		14	14·68	8					5½	2⅜	4 61/64	72	6·5	3·91
2⅝	4	2 5/16	16 ,,	62		15	15·68	8					5¾	2⅜	5 13/64	76	6·5	3·91
2¾	3½	2 13/32	15 ,,	62		16	16·68	8					6	2¼	5 7/16	80	7·0	3·63
2⅞	3½	2 33/64	14 ,,	62		17	17·68	8										
3	3½	2 41/64	13 ,,	56		18	18·68	8										
3⅛	3½	2 49/64	12 ,,	44														
3¼	3¼	2 55/64	⅛ in.	40														
3⅜	3¼	2 63/64	0·154	40														
3½	3¼	3⅛	0·175	32														
3⅝	3¼	3 15/64	3/16	32														
3¾	3	3 21/64	¼	26														
3⅞	3	3 29/64	0·266	26														
4	3	3 37/64	0·281	26														
4¼	2⅞	3 13/16	5/16	26														
4½	2⅞	4 1/16	⅜	26														
4¾	2¾	4 19/64	9/16	26														
5	2¾	4 7/16	1·0	26														
5¼	2⅝	4 49/64	1·29	24														
5½	2⅝	5 1/64	1·37	24														
5¾	2½	5¼	1 7/16	24														
6	2½	5½	1½	24														

The Whitworth sizes below ¼ in. are no longer British Standard.

APPENDIX II

Table of wire and plate gauge standards

B.G. = Birmingham Gauge for sheets and hoops.
A.W.G. = American or Brown and Sharpe Wire Gauge.
B.W.G. = Birmingham Wire Gauge or Stubs' Iron Wire Gauge.
S.W.G. = Standard Wire Gauge.
S.S.W. = Stubs' Steel Wire Gauge.

B.G.		A.W.G.		B.W.G.		S.W.G.		S.S.W.			
Designating numbers	Equivalents in in.	Designating numbers	Equivalents in in.	Designating numbers	Equivalents in in.	Designating numbers	Equivalents in in.	Designating numbers	Equivalents in in.	Designating numbers	Equivalents in in.
15/0	1·000	0,000	0·460	0,000	0·454	0,000,000	0·500	Z	0·413	28	0·139
14/0	0·9853	000	0·40964	000	0·425	000,000	0·464	Y	0·404	29	0·134
13/0	0·9167	00	0·3648	00	0·380	00,000	0·432	X	0·397	30	0·127
12/0	0·8750	0	0·32486	0	0·340	0,000	0·400	W	0·386	31	0·120
11/0	0·8333	1	0·2893	1	0·300	000	0·372	V	0·377	32	0·115
10/0	0·7917	2	0·25763	2	0·284	00	0·348	U	0·368	33	0·112
9/0	0·750	3	0·22942	3	0·259	0	0·324	T	0·358	34	0·110
8/0	0·7083	4	0·20431	4	0·238	1	0·300	S	0·348	35	0·108
7/0	0·6666	5	0·18194	5	0·220	2	0·276	R	0·339	36	0·106
6/0	0·625	6	0·16202	6	0·203	3	0·252	Q	0·332	37	0·103
5/0	0·5883	7	0·14428	7	0·180	4	0·232	P	0·323	38	0·101
4/0	0·5416	8	0·12849	8	0·165	5	0·212	O	0·316	39	0·099
3/0	0·500	9	0·11443	9	0·148	6	0·192	N	0·302	40	0·097
2/0	0·4452	10	0·10189	10	0·134	7	0·176	M	0·295	41	0·095
1/0	0·3964	11	0·090742	11	0·120	8	0·160	L	0·290	42	0·092
1	0·3532	12	0·080808	12	0·109	9	0·144	K	0·281	43	0·088
2	0·3147	13	0·071961	13	0·095	10	0·128	J	0·277	44	0·085
3	0·2804	14	0·064084	14	0·083	11	0·116	I	0·272	45	0·081

4	0·250	15	0·057068	15	0·072	12	0·104	H	0·266	46	0·079
5	0·2225	16	0·05082	16	0·065	13	0·092	G	0·261	47	0·077
6	0·1981	17	0·045257	17	0·058	14	0·080	F	0·257	48	0·075
7	0·1764	18	0·040303	18	0·049	15	0·072	E	0·250	49	0·072
8	0·157	19	0·03589	19	0·042	16	0·064	D	0·246	50	0·069
9	0·1398	20	0·031961	20	0·035	17	0·056	C	0·242	51	0·066
10	0·125	21	0·028462	21	0·032	18	0·048	B	0·238	52	0·063
11	0·1113	22	0·025347	22	0·028	19	0·040	A	0·234	53	0·058
12	0·0991	23	0·022571	23	0·025	20	0·036	1	0·2278	54	0·055
13	0·0882	24	0·0201	24	0·022	21	0·032	2	0·219	55	0·050
14	0·0785	25	0·0179	25	0·020	22	0·028	3	0·212	56	0·045
15	0·0699	26	0·01594	26	0·018	23	0·024	4	0·207	57	0·042
16	0·0625	27	0·014195	27	0·016	24	0·022	5	0·204	58	0·041
17	0·0556	28	0·012641	28	0·014	25	0·020	6	0·201	59	0·040
18	0·0495			29	0·013	26	0·018	7	0·199	60	0·039
19	0·044					27	0·0164	8	0·197	61	0·038
20	0·0392					28	0·0149	9	0·194	62	0·037
21	0·0349					29	0·0136	10	0·191	63	0·036
22	0·03125					30	0·0124	11	0·188	64	0·035
23	0·02782							12	0·185	65	0·033
24	0·02476							13	0·182	66	0·032
25	0·02204							14	0·180	67	0·031
26	0·01961							15	0·178	68	0·030
27	0·01745							16	0·175	69	0·029
28	0·015625							17	0·172	70	0·027
29	0·0139							18	0·168	71	0·026
30	0·0123							19	0·164	72	0·024
								20	0·161	73	0·023
								21	0·157	74	0·022
								22	0·155	75	0·020
								23	0·153	76	0·018
								24	0·151	77	0·016
								25	0·148	78	0·015
								26	0·146	79	0·014
								27	0·143	80	0·013

APPENDIX III

Patternmakers' tools and stores

List A.—For Work in the Field

Vocabulary Stores

Awls blades, brad, assorted		4
„ handles, brad, small		1
Bevels, steel blade, 9 in.		1
Braces, carpenters', ratchet, with 24 bits		1
Callipers, 5 in., inside and outside		1
Cans, oil, lubricating, with lever valve		1
Chisels, firmer, 1¼ in., 1 in., ¾ in., ½ in., ¼ in.	each	1
Compasses, wing		1
Dividers, spring, 6 in., Mark II		1
Files, saw, taper, second cut, single, 6 in. and 4 in.	each	1
Gauges, carpenters', marking		1
Gouges, handles, firmer, 1 in., ⅝ in., ⅜ in., ⅛ in.	each	1
Hammers, carpenters'		1
Oilstones, carpenters'		1
„ slips, Turkey		1
Pincers, carpenters'		1
Planes, jack		1
„ smoothing		1
Rules, G.S., 4-fold		1
Saws, dovetail, brass back		1
„ hand, 26 in.		1
„ keyhole, 9 in. blade and pad		1
„ tenon, 14 in.		1
Screwdrivers, G.S., 12 in.		1
„ R.E., 6 in.		1
Spokeshaves, 2½ in.		1
Squares, carpenters', 6 in.		1

N.I.V. Stores

Box, with lock, 18 in. × 10 in. × 10 in.		1
Chisels, swan-neck, ¾ in., ½ in., ¼ in.	each	1
Gouges, long, paring, inside ground, radii 3 in., 2 in., 1 in., ½ in., ¼ in., ⅛ in.	each	1
Gouges, swan-neck, ¾ in., ½ in., ¼ in.	„	1
Rules, contraction (iron and brass)		1

List B.—Additional to A, for Base Workshop

Vocabulary Stores

Mallets, carpenters'	
Planes, rabbet, square, 1 in., ¾ in.	each
Punches, centre, 4½ in., G.S.	

N.I.V. Stores

Chisels, long, thin, paring, 1½ in., 1¼ in., 1 in., ¾ in., ½ in., ⅜ in., ¼ in., ⅛ in.	each	1
Chisels, swan-neck, 1 in., ⅛ in.		1
Gouges, long, thin, paring, inside ground, ¾ in. radius		1
,, ,, ,, ,, outside ,, ¾ in. ,,		1
,, swan-neck, 2 in., ¾ in., ⅛ in. radius	each	1
Planes, round, 1¼ in., 1 in., ½ in.		1
,, Stanley		1
Squares, 12 in.		1

LIST C.—SHOP EQUIPMENT, HELD IN TOOL-ROOM

Vocabulary Stores

Brushes, hair, flat, 1½ in.	—*	
Cramps, carpenters', 5 ft.	—*	
Lathes, engineers', tools, hand, wood-turning—		
Chisels, ⅜ in., 1 in., 1½ in.	each	1
Diamond point		1
Pots, glue, 1 pint		1

N.I.V. Stores

Depth gauge		1
Gouges, ⅜ in., ¾ in., paring	each	1
Brown and Sharpe protractor		1

LIST D.—SHOP STORES

Dowels and sockets, assorted (N.I.V.)	—*
Glue, red and black paint, brads, methylated spirit, screws of sizes (brass), pale orange shellac, and glass paper	—*

* As required.

APPENDIX IV

Moulders' tools and stores

LIST A.—TOOLS

Boss, tool, double-ended	1
Brush, camel-hair	1
Callipers, inside and outside	1
Cleaners, $\frac{1}{2}$ in. and $\frac{3}{8}$ in.	2
Fillet tool	1
Knife, gate (or heart square)	1
Lug tool	1
Rammer, flat	1
,, peg	1
Rule, 2-ft.	1
Slickers, flange	1
,, pipe	1
,, square	1
Spoon tool	1
Trowel, moulders'	1

LIST B.—FOUNDRY EQUIPMENT AND STORES FOR USE IN MOULDING

Equipment

Bellows, hand.

Boxes, moulding, of sizes.

Sieves, mesh $\frac{1}{16}$ in., $\frac{1}{12}$ in., $\frac{1}{8}$ in., $\frac{1}{4}$ in.

Shovels, buckets, water cans, oil cans, wheelbarrow, turn-over boards, loam trestles, core oven (of sorts), core benches, and grinding mill for sand (in permanent shops).

APPENDIX V

Blacksmiths' tools and stores

Articles	Trade name	Reference to figures, and remarks
Hammers, fitters', 32 oz. ..	—	Pl. **8**, Fig. 2.
„ „ 24 oz. ..	—	Pl. **18**, Fig. 1.
„ smiths', sledge, 10 lb.	—	Pl. **8**, Fig. 3.
„ „ uphand, 7 lb. ..	—	—
„ set	Set hammers	N.I.V.
Handles, file, large	—	—
Holders, rivet head	—	—
Punches, smiths', hot, $\frac{3}{8}$ in., $\frac{1}{2}$ in., and $\frac{5}{8}$ in.	—	Pl. **8**, Fig. 24.
Rasps, rough, half-round, 12 in.	—	—
Rules, smiths', 2-fold ..	—	—
Saws, hack, 12 in. frame and blades	—	—
Snaps, riveting, rod, $\frac{1}{2}$ in. to 1 in.	—	—
Square, smiths', 2 ft. × 1 ft.	—	—
Tongs, smiths', forebit ..	—	The smith will make any others himself.
„ hollow bit	—	
„ forge	—	
„ plier, Mark II ..	—	
Tools, forming (4 grooves) ..	Swages ..	A selection of these is required, bearing in mind the many equivalent bottom tools in the swage block.
„ rounding, Mark II, top and bottom	„ ..	
Vices, standing, *80 lb. ..	—	—

* The chest, tool, smiths', filled, contains a number of tools not required by the R.E. smith.

Tools that may be required for general shop use in a smithy

Articles	Remarks
Bending block	Pl. **9**, Fig. 13.
Cold punching and shearing machine, either hand or power driven	—
Hammer, power, 10 cwt.	—
Hand or power drilling machine (up to 1 in.)	—
Mandrel, sugar-loaf	—
Set of cold bending rollers	—
Stand, adjustable	Pl. **8**, Fig. 26. Can be made in the shop.

APPENDIX VI

Personal tools required by a boilermaker

Chest, tool, empty, with padlock, No. 11	No.	
Bevels, steel, 9 in. (N.I.V.)		
*Braces, ratchet, 18 in.		
* „ „ drills, ¼ in. to 1½ in. (11 drills)	Set	
* „ „ „ tapping, ⅜ in. to 1 in. (6 drills)	„	
* „ „ posts, 24 in.	No.	
Callipers, 8 in., outside	Pair	
„ 8 in., inside	„	
Cans, oil, lubricating, G.S.	No.	
Chisels, cross-cut, 7 in. × ¼ in.		
„ engraving, 9 in., diamond point		
„ hand, cold, ⅞ in. × 9 in.		
Compasses, wing, 12 in.	Pair	
Cramps, fitters', 5 in.	No.	
Drifts, steel, round, ⅜ in. (N.I.V.)		
½ in.		
⅝ in. (N.I.V.)		
¾ in.		
⅞ in.		
1 in.		
2½ in., tube-expanding (N.I.V.)		
Files, bastard, flat, 14 in.		
half-round, 14 in.		
hand, safe edge, 14 in.		
round, 14 in.		
Fullers, boilermakers' (N.I.V.)		
Hammers, fitters', 32 oz.		
„ riveting, boilermakers', 3½ lb.		
* „ „ holding-up, 14 lb. (N.I.V.)		
* „ smiths', uphand, 7 lb.		
Handles, file, large		
Holders, rivet head, large		
Punches, centre, 4½ in.		
Rules, armament artificers', 2 ft.		
Saws, hack, 12 in.	„	1
„ „ blades	„	3
Scribers, steel	„	1
Snaps, riveting, rod, 1⅝ in., 1½ in., 1⅜ in., 1⅛ in., ⅞ in., ¾ in.	Set of	6
Spanners, adjustable, 15 in.	No.	1
Squares, fitters', 6 in.	„	1
Tools, caulking, straight face (N.I.V.)	„	1
„ „ rivet (N.I.V.)	„	1
*Tools, reaming and tapping stays, boilermakers', ⅝ in. (N.I.V.)	„	1
*Tools, reaming and tapping stays, boilermakers', ¾ in. (N.I.V.)	„	1
*Tools, reaming and tapping stays, boilermakers', ⅞ in. (N.I.V.)	„	1
*Tools, reaming and tapping stays, boilermakers', 1 in. (N.I.V.)	„	1
*Tools, reaming and tapping stays, boilermakers', keys (N.I.V.)	„	1
*Tools, expanding tubes, roller		1

Stores

Bolts, with nuts, hexagon head, ½ in. × 3¼ in., fully threaded	No.	12
Paper, stiff, for templets (N.I.V.)	Sheets	2
Red lead, mixed (N.I.V.)	Lb.	1
Sal-ammoniac, small grain	,,	1

NOTE.—Tools marked * will normally be kept in store, and only drawn when required for a specific job, or by a party proceeding on detachment duty.

APPENDIX VII

Tools required by a fitter and fitter driver, R.E.

Wooden box with lock and key, about 18 in. long × 10 in. × 10 in.	No.	1
Callipers, 5 in., inside	Pair	1
„ 5 in., outside	„	1
Cans, oil, lubricating, G.S., with lever valve	No.	1
Card, scratch	Foot	½
Chisels, cross-cut, 7 in. × ¼ in.	No.	1
„ „ 4½ in. × ⅛ in.	„	1
„ hand, cold, 8 in. × ¾ in.	„	1
„ „ „ 6 in. × ½ in.	„	1
„ round nose	„	1
Cloth sponge	„	1
Dividers, spring, 6 in., Mark II	„	1
Files, bastard, half-round, 12 in.	„	1
„ „ hand, safe edge, 14 in.	„	1
„ „ round, 12 in.	„	1
„ „ „ 8 in.	„	1
„ „ square, 10 in.	„	1
„ second cut, half-round, 12 in.	„	1
„ „ „ hand, safe edge, 12 in.	„	1
„ smooth, half-round, 8 in.	„	1
„ „ hand, safe edge, 6 in.	„	1
Hammers, fitters', 16 oz.	„	1
Handles, file, large	„	1
„ „ middling	„	1
Pliers, side-cutting, 8 in.	Pair	1
„ round nose	„	1
Punches, centre, 4½ in.	No.	1
„ pin, $\frac{3}{16}$ in.	„	1
Rules, armament artificers', 12 in.	„	1
Saws, hack, 12 in., with three blades	„	1
Scrapers, bearing (N.I.V.) (*see* M.T. Vocabulary)	„	4
Screwdrivers, G.S., 9 in.	„	1
„ „ 4 in.	„	
Spanner, armament artificers', double-ended, ¼ in. and $\frac{3}{16}$ in.	„	1
Spanners, armament artificers', double-ended, $\frac{7}{16}$ in. and $\frac{5}{16}$ in.	„	1
Spanners, armament artificers', double-ended, ½ in. and ⅜ in.	„	1
Spanners, armament artificers', double-ended, ⅜ in. and ¾ in. (N.I.V.)	„	1
Spanners (box), socket, double-ended, ¼ in. and ¾ in. (N.I.V.)	Set	1
Spanners, magneto (N.I.V.)	No.	1
„ adjustable, 11 in.	„	1
Squares, fitters', 6 in.	„	1
Vices, hand, combination	„	1
Wrenches, adjustable, 9 in. (footprint)	„	1

INDEX

A.

B.

C.

D.

E.

G.

J.

M.

N.

O.

P.

S.

T.

U.

V.

W.

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